METALLURGIA

THE BRITISH JOURNAL OF METALS

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METALLURGIA

THE BRITISH JOURNAL OF METALS
INCORPORATING THE METALLURGICAL ENGINEER

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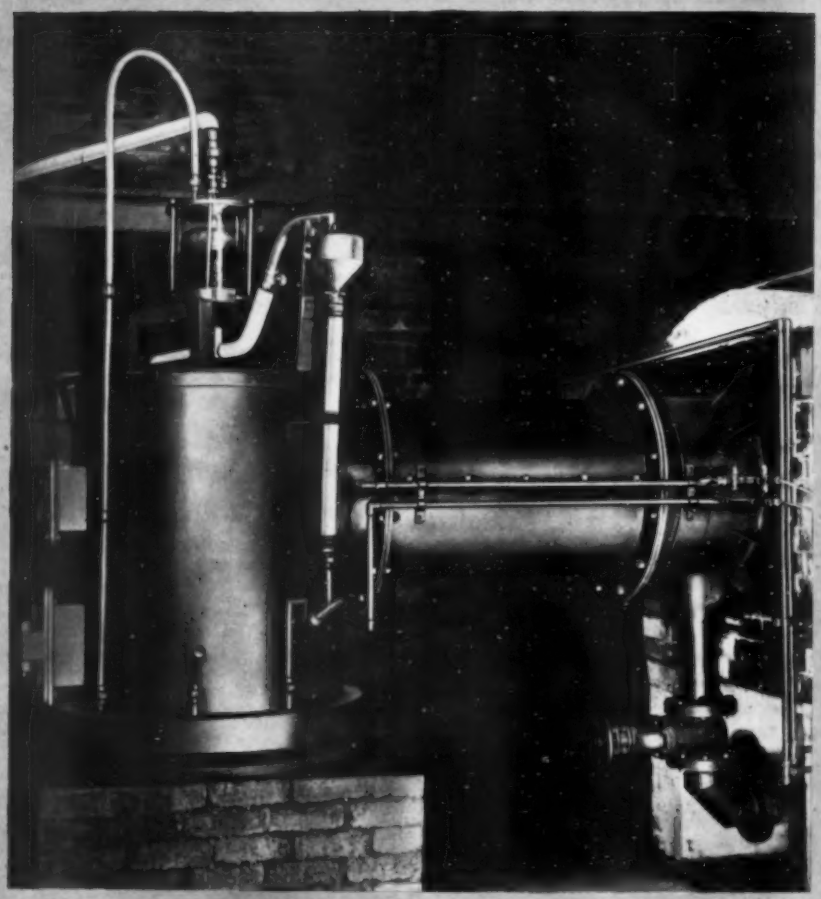

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METALLURGIA

THE BRITISH JOURNAL OF METALS

INCORPORATING THE "METALLURGICAL ENGINEER"

MAY, 1956 Vol. LIII. No. 319

Automation

WHETHER the recent dispute at the Standard Motor Company's factory at Coventry arose from questions of automation or the redundancy of 3,500 men during the period of retooling the tractor works—and there have been differences of opinion on this point—one of the principal results has been an awakening of interest in the whole question of automation and its consequences. The term automation was first widely publicised by Mr. John Diebold, who gave the credit for its introduction to Mr. D. S. Harder, Vice-President for Manufacturing, Ford Motor Company, U.S.A. Mr. Harder used it to describe the automatic handling of parts in and out of machines, and has more recently defined it as "the automatic handling of parts between progressive production processes."

It must be realised that automatic operation is not new, as many process plants in various industries have been subject to automatic control, in whole or in part, for a long time. What is new is the extension of automatic operation to "the hard, heavy, awkward and unyielding shapes of those components used in industries based on engineering practice"—as Mr. F. G. Woollard put it in his paper to the Institution of Production Engineers' Conference on the Automatic Factory at Margate last year—the adoption of controls (electronic or otherwise) and the institution of feed-back apparatus and servo-mechanisms to ensure that accuracy is maintained within pre-determined limits.

Although the automatic factory—what the Americans call ultimate automation—is unlikely in the metal-working industries for some years (if ever), it is a distinct possibility in the case of materials which are liquid, or fluid, or which flow easily. Automation is capable of great economies in manpower, floor space, inventory and machine utilisation, and it promises, by automatic inspection, to give an ever-closer control over accuracy of the product. It must not be thought, however, that automation is capable of universal application: there are many operations which can be more economically performed by manual labour, and automation will only be adopted where there is economic justification for so doing; where the requisite labour force is not available; and where the safety of the workers demands it, as in nuclear energy projects. The last two are, in a way, special cases of the first.

We, in this country, have to import half our food and many of the raw materials for our manufactures, and in order to do this we must export an appreciable fraction of our industrial output. It has been stated, for instance, that 40% of our engineering products need to be exported to help pay for our imports. Contrary to the view held by some in this country, the world does not consider itself to owe us a living. In consequence, we must sell our exports in a competitive market, in which there are two rivals against whom competition is difficult, namely, those who are prepared to accept a lower standard of living than we enjoy, and those who are prepared to accept a lower standard of leisure than we are. In the field of novelties and quality products, we may be able to hold our own against such opposition, but can we live by exports of this type alone? As novelties are often the forerunner of mass production lines, their continued development is essential, as are new ideas in any sphere of human activity, but we must have bread-and-butter business, to-day's profits from which will support the development of the novelties and quality products which will themselves provide the bread-and-butter business of to-morrow.

As Lord Halsbury pointed out at the Automatic Factory Conference, we can only defend our standard products—our automobiles, textiles, etc., which sell for export in sterling units of a hundred million—against the competition of our rivals by using more advanced manufacturing techniques. We have a fine record in the production of new ideas, the development of prototypes of all kinds, and the evolution of new equipment, but we are not quite so good at exploiting these ideas on a large scale, and America has a good lead over us in this respect. In Europe, too, our competitors make good progress. France has gone ahead in the motor car industry, and the rapid development of German industry has resulted in her taking the lead in certain fields. Nor is automation neglected behind the iron curtain—Russia now has a Ministry of Automation, indicating the importance attached to it. A continuance of our present production methods in certain fields, together with continued increase in wages, can only result in our pricing ourselves out of world markets. World demand for new goods at low prices is expanding, but only if our prices are right can we expect to share in meeting that demand. As a technique whereby standard products can be made and sold in competition with similar products marketed by other countries, automation is essential to the continued maintenance of our position in the world. It is essential to us, and we cannot afford not to exploit it as intensively as we can.

One of the main problems to be faced is the redeployment of employees in factories where redundancy arises as a result of automation. Because of this, it is essential that the Government and the two sides of industry should make themselves familiar with the issues involved, and it is hoped that the report to be published shortly by the Department of Scientific and Industrial Research will give detailed guidance on the type of problem likely to be encountered. American union leaders have studied the subject thoroughly, including the likely benefits in terms of lower production costs, and, as a result, have been able to bargain intelligently with the employers about the share likely to be given to the workers in the form of higher wages. On the other hand, they have been able to convince their members that

there are solid long-term gains, as well as short-term discomforts, to be derived from the new development, which can lead to an increase in real wages—that is, one which will not be offset by rising prices.

Once the workers are satisfied that automation is not basically evil, and that it has a great potential for good, its introduction will proceed more smoothly, particularly if full overall employment is maintained. That is not to say that occasional and localised redundancy will not arise: it is, therefore, of the utmost importance that employers, Unions and Government co-operate in such a way as to make redeployment as easy as possible for those affected. This co-operation is most likely to be achieved if firms contemplating the introduction of automation consider from the beginning how it is likely to affect their workers, and bring them into early discussions on the subject.

Personal News

SIR BEN LOCKSPEISER, K.C.B., F.R.S., has joined the Board of Tube Investments, Ltd., and has been appointed Scientific Adviser to the Tube Investments Group.

MR. W. J. SOMMERVILLE, London Manager of the Fraser and Chalmers Engineering Works of The General Electric Co., Ltd., has retired after 36 years with the Company.

PROFESSOR E. C. ROLLASON is relinquishing the Henry Bell Wortley Chair in Metallurgy at Liverpool University, to take the Chair of Industrial Metallurgy at Birmingham University in September of this year.

THE DISTINGTON ENGINEERING CO., LTD., announce that MR. T. WINTRUP, hitherto described as Sales Manager (Engineering), will in future be known as Sales Manager (General Engineering).

MR. R. BARBER, Head of the Research Department of Land Pyrometers, Ltd., Sheffield, recently read a paper to the Committee for the Study of High Temperature Techniques in Düsseldorf, on the subject of Gas Temperature Measurement.

SIR BERNARD KEEN, F.R.S., and MR. A. G. P. POWELL have been elected to the Board of Baird and Tatlock (London), Ltd., and MR. W. C. JOHNSON, M.B.E., and MR. H. N. RICKETTS have been elected to the Board of Hopkin and Williams, Ltd.

JOHNSON, MATTHEY AND CO., LTD., announce the appointment of MR. H. J. TAYLOR as Manager of the Company's Hadyn Park Works at Shepherds Bush, where he succeeds MR. A. GODDEN.

MR. W. J. DONNELLY, who had been appointed Technical Representative, Midlands Area, for the Scientific and Industrial Division of Sunvic Controls, Ltd., has now been transferred to the Application Engineering Department at the Works, Harlow, Essex.

MR. S. R. HOWES, at present Director and General Manager of Samuel Fox and Co., Ltd., is to retire at the end of June. Mr. Howes, who will be succeeded by MR. H. P. FORDER, at present Director and Deputy General Manager of the Branch, will remain on the Board of the Company

MR. R. S. MEDLOCK, Head of the Research and Development Department of George Kent, Ltd., has been appointed to the Board of the Company.

FOLLOWING the appointment as Local Directors of Hadfields, Ltd., of MR. F. A. BAILEY (Engineering Controller), MR. E. H. BOOTH (Forgings Technical Manager), MR. H. COTTON (Manager, Sales Department), MR. K. B. CROMPTON (Chief Cost Accountant), MR. J. F. SQUIRE (General Sales Manager), MR. F. WARRILOW (Secretary) and MR. G. WOOD (Heat Treatment Superintendent), Local Directors and Directors of the Company have now been appointed to the Boards of three subsidiary companies to bring them up to strength. MR. E. W. COLBECK becomes Managing Director of Hadfields Steels, Ltd., of which Company MAJOR H. G. FREEMAN, MR. J. H. SQUIRE and DR. J. R. RAIT are appointed Directors. Appointments to the Board of Hadfields Forgings, Ltd., of which MR. A. H. WAINE becomes Managing Director, are MR. R. LAMB, MR. G. WOOD, MR. E. H. BOOTH and MR. J. F. SQUIRE. The new Managing Director of Hadfields Foundry and Engineering, Ltd., is MAJOR H. J. FREEMAN, who is joined on the Board by MR. J. F. SQUIRE and MR. F. A. BAILEY. The three subsidiary Companies are all operating Companies with the Parent Company responsible for sales. MR. D. R. WARD, Personal Assistant to the Financial Director and Secretary, has been appointed Assistant Secretary of Hadfields, Ltd., and MR. A. AIKEN has been appointed Assistant Publicity Manager.

AIR CHIEF MARSHAL, SIR JOHN N. BOOTHMAN, K.C.B., K.B.E,. D.F.C., A.F.C., has joined the Board of Kelvin and Hughes, as Technical Sales Director.

MR. G. A. G. IVE has been appointed Manager Director of Radiovisor Parent, Ltd., in succession to the late MR. E. H. BELL.

MR. H. R. BIRKINSHAW, who joined the firm in 1917, has been appointed Manager of the London Office of Edgar Allen and Co., Ltd., in succession to MR. H. R. BEKEN.

MR. L. H. WALKER has left the United Kingdom to take up an appointment with the Reynolds Metals Co., of Louisville, Kentucky, U.S.A. He was formerly with Imperial Chemical Industries, Ltd., Metals Division, Birmingham.

MAJOR W. R. BROWN, D.S.O., has been elected Vice-Chairman of the Board of The Power-Gas Corporation, Ltd., of Stockton-on-Tees, and MR. T. K. HARGREAVES, D.S.O., has been appointed a Director of the Company.

Obituary

WE regret to record the death of Mr. VERNON YOUNG, Director of International Combustion (Holdings), Ltd., and Chairman of its subsidiaries, International Combustion, Ltd., International Combustion Products, Ltd., and Riley (IC) Products, Ltd., who died after a short illness on April 18th at the age of 64. Mr. Young joined the Organisation in 1924 as Secretary, a position he held until shortly before his death, when he resigned owing to ill health. He was appointed a Director of International Combustion (Holdings), Ltd., in 1952, and Chairman of International Combustion, Ltd., and International Combustion Products, Ltd., in 1955.

Loewy Mill Order

THE Loewy Engineering Co., Ltd., has secured an order from The Patent Shaft & Axletree Co., Ltd., of Wednesbury, for a complete blooming and slabbing mill and a plate mill worth over £1·5 million, to be delivered by mid-1958.

The Composition and Reduction of Oxide Films on Copper

By R. F. Tylecote, M.A., M.Sc., Ph.D., F.I.M.*

By carrying out reductions of copper oxide films at the temperature of formation, in an atmosphere consisting of a mixture of nitrogen and hydrogen, the proportion of cupric oxide in films formed on copper at temperatures between 270 and 850° C. has been determined. The reduction rate of cupric and cuprous oxide to copper was estimated in the course of this work, and the mechanism of oxidation and reduction is discussed.

DURING the course of work on the oxidation of copper carried out by the author, the need has been felt for a reliable method of analysis of the resulting oxide film. This must be free from the objections to most of the methods available, involving cooling the oxide to room temperature or reducing the oxygen pressure, which may result in changes in the composition of the film due to oxidation during cooling, or to solid phase reactions within the film.

The method used in this work was to carry out reductions of copper oxide films, at the temperature of formation, in an atmosphere consisting of a mixture of nitrogen and hydrogen in varying proportions. In this way the proportion of cupric oxide has been determined in films formed on copper between 270 and 850° C. In the course of these estimations the reduction rate of cupric and cuprous oxide to copper was determined.

Previous Work

Oxide films formed on high purity copper in air or oxygen at temperatures above about 200° C. consist of two layers, the upper of CuO and the lower of Cu_2O. Recent work has shown that these layers are porous, but not deeply fissured, even after cooling. There is, however, a tendency for films formed below 600–700° C. to be exfoliated at quite high temperatures during cooling, which may result in a change in their composition.

Films formed at temperatures above 800° C. consist mainly of Cu_2O, while those formed at intermediate temperatures of 700°–500° C. contain about 50% of CuO. There exists a considerable difference of opinion regarding the composition of films at lower temperatures—the relative amounts of the two oxides depending on the experimental conditions. According to Valensi,[1] who confirmed his theoretical figures with experimental data, the compositions should be as in Table I.

Since the scales tend to exfoliate on cooling, leaving a thin film of residual Cu_2O on the surface, analysis of the exfoliated scale itself is not sufficient. Valensi first determined the loss of weight of the exfoliated scale after reduction in hydrogen at 800° C. and obtained an upper limit for the CuO content from this. He then polished the metal surface slightly to remove the residual Cu_2O, and obtained a lower limit for CuO by calculation of the total weight loss of the specimen. The two figures were found to differ by from 10–20%, and the experimental figures given in Table I represent the mean.

As regards the effect of oxidation time on composition, Valensi made a series of measurements for three film thicknesses varying over the range 8·8–34 mg./sq. cm. at 860° C., and deduced that composition was independent of time (= 7% CuO). However, more recently, Dankov and Ignatov[2] have shown, by electron diffraction, that at 200° C. the superficial CuO content during oxidation in air changes from very little after 5–10 minutes to a maximum after 25 minutes. After 150 minutes no CuO was found in the superficial film.

TABLE I.—COMPOSITION OF FILMS FORMED ON HIGH PURITY COPPER IN AIR OR OXYGEN.

Oxidation Temperature (° C.)	% CuO	
	Calculated	Experimental
900	10·0	5·0
860	—	7·0
700	20·0	50·0
600	37·0	60·0
500	75·0	80·0
300	98·0	95·0

Dravnieks[3] found that, for oxidation in pure oxygen with a pressure of 760 mm. Hg at 500° C., the CuO content reached 95% after 17 hours. At lower pressures, the CuO content gradually increased with thickness, reaching 35% for a pressure of 2·0 mm. Hg and 10% for a pressure of 0·5 mm. Hg upon attaining a thickness of 9×10^{-4} cm. in both cases. At 600° C., Dravnieks found for the two lower pressures that CuO appeared in the scale much later than at 500° C. Between 600 and 690° C. (i.e., maximum temperature), Dravnieks thought that the CuO film was not continuous.

Dennison and Preece[4] showed that at 650° C., in air, the CuO content of films on tough-pitch copper increased from zero for times up to 5 hours to about 35% after 100 hours. Furthermore, it appeared that at all temperatures the CuO content was somewhat higher after 48 hours than after 24 hours. These results tend to conflict with Valensi's results, possibly due to the fact that the technique used was intended to determine the composition of the loosened upper layers of the film only, and not the adherent lower layer rich in Cu_2O. Calculations made on the basis of work previously reported by the author[11,12] show that, at 700° C., the part of the film exfoliated represents only 49% of the total weight of film, and has a CuO content of 35%, whereas the CuO content of the whole oxide film is only 20%.

Gulbransen and McMillan[5] carried out electron diffraction work on copper oxide films and found that the CuO content rose from a trace after 1 minute's oxidation at 300° C. to 100% CuO after 60 minutes at 760 mm. Hg. pressure of oxygen. At 500° C., CuO was definitely observed at 1 minute and reached 100% after 30 minutes. These figures, of course, only apply to the outer surface layers of the film, and do not preclude a substantial

* Department of Metallurgy, King's College, University of Durham, Newcastle upon Tyne, 1.

Fig. 1.—General view of autographic thermobalance.

Courtesy of the Journal of the Institute of Metals.

layer of Cu_2O being present underneath in all cases. During cooling, or holding under vacuum, they observed a decrease in the amount of CuO, and concluded that the reaction :

$$CuO + Cu^+ + e^- = Cu_2O + Cu^+\square + e^-\square$$

was occurring on the CuO-Cu_2O interface.

The results of other workers on the oxidation of copper at low temperatures (20°–250° C.) showed that the CuO content increased with both time and temperature. Bouillon[6] found no trace of CuO in films formed at 173° C. after 180 minutes, while at 247° C. CuO began to be apparent after 30 minutes ($2{\cdot}6 \times 10^{-5}$ cm.) and increased in amount after longer periods.

Summarizing the available information on composition, it appears that the content of CuO in copper oxide films rises from zero at room temperature to a maximum between 300 and 500° C. and falls off to zero again as it approaches the dissociation temperature of the cupric oxide. The information on the effect of time is conflicting ; it appears that at low temperatures there is a gradual increase in the CuO content with time. At the higher temperatures (>500° C. at N.P.), the composition seems to be constant after fairly long times. Reduction of pressure decreases the CuO content markedly at 500° C. and also increases the time required to reach the maximum CuO content.

As far as the author is aware, no extensive work has been done on the mechanism or kinetics of reduction of copper oxide films, but sufficient has been done on wüstite to indicate a possible mechanism in the case of copper.

According to Gellner and Richardson,[7] the first stage is the reduction of the oxide on the surface to metal, which may or may not sinter to the massive form. If sintering takes place, the reduction of the inner layers of oxide by the reducing gas will be slowed down, since both the hydrogen and the water vapour will have to move through the metallic layer. This will tend to increase that part of the reduction caused by diffusion of metal from inside the film.

According to Richardson and Dancy,[8] the reduction of CuO proceeds by the formation of metallic copper on the surface, without the inward diffusion of metallic ions which occurs in the reduction of wüstite. This is because, in copper oxides, the number of vacant cation sites is not sufficient to permit the rapid diffusion necessary. Therefore, it would be expected that the copper would nucleate on the outer surface, giving a rapid rate of reaction, since the volume of the reduced copper will be less than the oxide. When the Cu_2O layer is reached, it would be expected that there would be a marked change of reaction rate due to the lower dissociation pressure of Cu_2O.

A certain amount of work has been done on the reduction of oxide powders. Pease and Taylor[9] investigated the reduction of cupric oxide powder in pure hydrogen ; and found that complete reduction of a sample at 150° C. took over 24 hours, while at 200° C. it was completed in 4 hours. The reaction took place at the Cu/CuO interface, and the presence of pre-existing copper nuclei accelerated the reaction. In the absence of copper nuclei, the presence of a small amount of moisture slowed down the rate of nucleation, but had no other effect upon the reaction.

Experimental Technique

The basis of the method used is the fact that CuO can be reduced by hydrogen to copper more readily than can Cu_2O, so that when a curve of weight loss against time is obtained, the transition between the reduction of CuO and that of Cu_2O is shown by a change of slope.

The apparatus is substantially that reported in a previous paper,[10] and shown in Fig. 1. It consists of an autographic thermobalance with a means of reducing the oxidised specimens in a mixture of nitrogen and hydrogen and recording the oxidation and reduction curves.

An electrolytically polished specimen of high purity vacuum melted copper, the composition of which is given

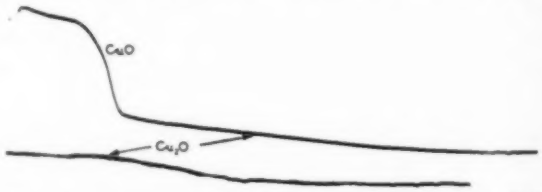

Fig. 2.—Reduction of mixture of CuO (52%) and Cu_2O powder at 270° C. in a nitrogen-hydrogen atmosphere.

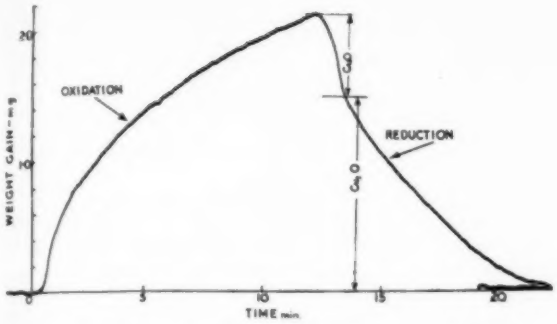

Fig. 3.—Oxidation of pure copper in dry air, and reduction in dry hydrogen-nitrogen mixture at 670° C. (Specimen area, 2·71 sq. cm.).

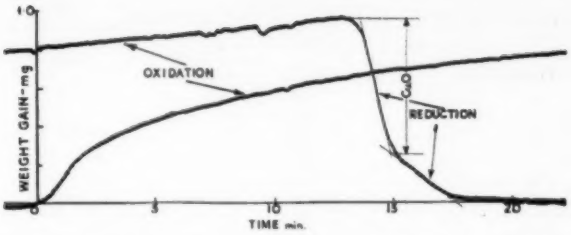

Fig. 4.—Oxidation of pure copper in dry air and reduction in moist hydrogen-nitrogen mixture at 570° C. (Specimen area, 1·55 sq. cm.).

in Table II, was inserted in the reaction chamber and heated to temperature in a mixture of dry hydrogen and nitrogen (hydrogen = 16% by vol.). When the required temperature was reached, the hydrogen and nitrogen were cut-off and oxidation carried out in dry air for the required time. When the required film thickness had been produced, " oxygen-free " nitrogen was introduced, and 2 minutes later hydrogen was added to the gas stream to effect the reduction of the oxide layer. The ratio of the two gases was varied according to reduction rates required.

TABLE II.—COMPOSITION OF HIGH PURITY COPPER.

Element	Percentage Weight
Oxygen	0·0001
Silver	0·0005
Phosphorus	Nil
Nickel	0·0001
Iron	0·0002
Lead	0·0005
Antimony	0·0002
Arsenic	<0·002 if any

In the early stages of the work, the reduction gases were passed through a water saturator at room temperature. The aim of this was to incorporate a small amount of water vapour in the gas stream in order to reduce the nucleation rate of the new phase, as found by Pease and Taylor.[9] It was hoped that this would make the change of slope between the reduction of CuO and Cu_2O sharper, but there was no evidence that this did in fact occur, and the practice was abandoned later in the work.

The partial pressure of oxygen in the atmosphere of " oxygen-free " nitrogen admitted to the reaction chamber was less than 8×10^{-3} mm. Hg.

Copper oxide powders were used to determine the conditions under which rapid reduction of CuO could be made to occur with a slower rate of reduction of Cu_2O, and in order to check the accuracy of the method used for the reduction of oxide scales. The powders used were normal laboratory reagent grades and contained moisture. The moisture content was determined by heating a sample at 300° C. in dry oxygen and absorbing the moisture removed on " Anhydrone." By this method, the sample of " CuO " powder was found to contain 3·7% H_2O, while the " Cu_2O " contained 0·456% H_2O.

The oxygen contents of the reagent grade oxides were determined by measuring the weight loss of 5–10 g. samples on heating in pure dry hydrogen in a combustion boat at 600°–700° C. for 3 hours. The weight loss of the " Cu_2O " powder was 12·9% giving after correction for moisture content a composition of 15% CuO, 85% Cu_2O.

In the same way the composition of the " CuO " powder was found to be 90% CuO, 10% Cu_2O.

The presence of CuO in the " Cu_2O " powder is probably accounted for by oxidation during storage and, therefore, it will be present as a thin film on the surface of the grains of Cu_2O. The presence of Cu_2O in the " CuO " powder is less easy to account for, but it is probable that it is due to unoxidised Cu_2O within the particles. Also, there is the possibility that the deficit of oxygen may be due to free copper.

The continuous reduction of these powders, and of a mixture of the two containing 52% CuO, according to the above method of analysis, was observed by means of the autographic thermobalance. Fig. 2 shows a typical continuous reduction curve for the mixture containing 52% CuO.

The reduction of samples weighing about 10 mg. was carried out in a small crucible of pure oxygen-free copper suspended in the reaction chamber of the balance. The atmosphere used was a mixture containing 68·7% nitrogen, 12·7% hydrogen and 18·6% water vapour by volume at N.T.P. This mixture was passed over the crucible at a rate of 17·0 l./hr. The specimens were quickly heated up to 270° C. in the reducing atmosphere, and it would be expected that the moisture present would be removed during this period.

It was found that CuO could be reduced at a rapid rate at 270° C. with negligible reduction of the Cu_2O. Increasing the temperature to 500° C., after reduction of the CuO appeared to be complete rapidly increased the rate of reduction of the Cu_2O.

The results obtained by reduction in the thermobalance, compared with the actual compositions, are given in Table III : it will be seen that agreement is good. In the case of mixed powders, reduction is taking place under the most difficult conditions, as far as the determination of composition is concerned, and some overlapping would be expected to occur. In the case of oxide films in which the oxides are arranged in definite layers, the line of demarcation might be expected to be clearer than in the case of intimately mixed powders.

In order to avoid high rates of reduction at higher temperature, a gas mixture with a lower hydrogen

TABLE III.—COMPARISON OF RESULTS OBTAINED BY THERMOBALANCE WITH ACTUAL COMPOSITION.

Sample	Powder	Composition—% CuO	
		By Analysis	From Thermobalance Reduction Curve
11	" CuO "	90	89
12	" CuO "	90	92
8, 9, 10	" Cu_2O "	15	13, 16, 19
6	" Cu_2O " + " CuO "	52	48
7	" Cu_2O " + " CuO "	52	50

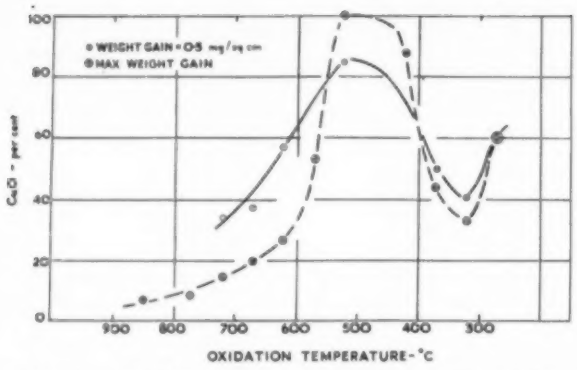

Fig. 5.—Variation of film composition with oxidation temperature. Reduced at temperature of oxidation.

content was used. The mixture mainly used consisted of 88% nitrogen and 12% hydrogen by volume.

Experimental Results

Typical oxidation and reduction curves are shown in Figs. 3 and 4. These relate to short time oxidation at 670° C. and 570° C., respectively. For longer time oxidations, only the reduction curve was recorded. The proportions of CuO and Cu_2O were readily determined from the curves together with the rates of reduction of CuO.

The Effect of Oxidation Temperature on Film Composition

Above about 400° C., the composition of the oxide films changed with temperature in much the same way as that found by Valensi.[1] The results are plotted in Fig. 5. Since there seemed to be a variation in composition with oxidation time, and hence weight gain, two curves are plotted: (1) for a given weight gain, i.e., 0·5 mg./sq. cm.; and (2) for a weight gain at which the proportion of CuO remained constant. It appeared that changes in composition with time occurred mainly in the early stages of oxidation, and there was found to be a constant CuO content which was gradually approached at each temperature. In cases where the constant value has not been obtained, or is in doubt, the value obtained for the thickest film has been inserted.

The Effect of Oxide Film Thickness on Composition

Although Valensi found no change in composition after long periods of oxidation at 860° C., others have reported a variation in composition with time at lower temperatures. Since scale characteristics are determined by thickness rather than time, it seems more logical when relating composition and time, to plot weight gain against composition.

TABLE IV.—EFFECT OF ATMOSPHERE ON COMPOSITION.

Atmosphere	Temperature (° C.)	Wt. Gain (mg./sq. cm.)	CuO (%)
Dry oxygen	720	0·93	25
Dry air	720	0·81	26
O.F. nitrogen	720	1·08	12
Dry oxygen	320	0·40	29
Dry air	320	0·35	47

Figs. 6 and 7 show the effect of weight gain on composition over a wide temperature range. At most temperatures, there seems to be a gradual reduction in CuO content with increasing weight gain. It is very difficult in practice to obtain points for low weight-gains (<0·5 mg./sq. cm.) at temperatures above 670° C., since the oxidation rates are so rapid that the time required is less than 5 minutes. The curves at 620° C. and 320° C. show the reduction in CuO content clearly, while the curves for 670° C. and 720° C. are less convincing. It is clear from these results why Valensi found no change in composition at 860° C. after long times. The two curves for 520° C. and 270° C. seem to show a gradual rise in CuO content. In fact, these results agree with those of Dravnieks[3] (500° C. in oxygen) and Bouillon[6] (247° C. in oxygen).

Effect of Oxygen Pressure on Film Composition

Oxidation in commercial purity oxygen at 720° C. gave a film containing 25% CuO, compared with 26% for an air-formed film of the same thickness, thus showing virtually no difference at this temperature. At 320° C. the film formed contained 29% of CuO, whereas that formed in air contained 47%. This can be explained on the basis of previous work,[10] which showed that films formed at such temperatures in air contained numerous blisters, which would obstruct the outward movement of copper ions. Films formed in oxygen seemed to be less porous, and gave closer agreement with the parabolic law in the early stages.

Oxidation in " oxygen-free " nitrogen at 720° C. gave a film containing only 12% CuO, compared with 26% for an air-formed film of the same thickness. In order to arrive at approximately the same weight gain, specimens were oxidised for much longer times in " O.F. " nitrogen than in air or oxygen.

The results are summarized in Table IV.

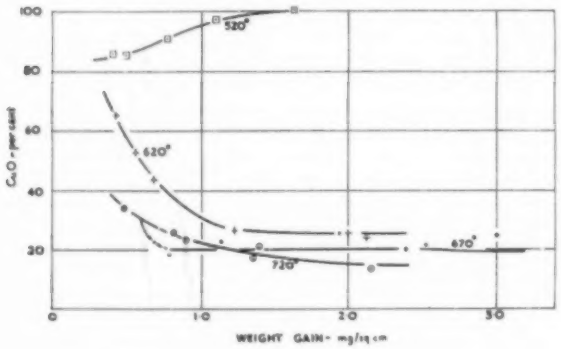

Fig. 6.

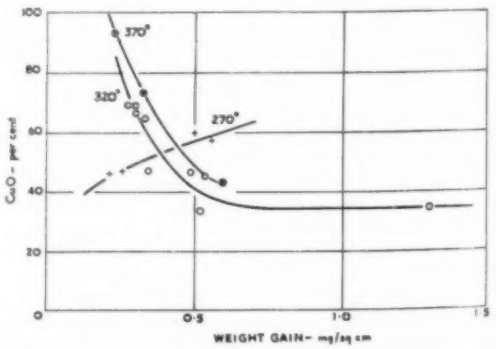

Fig. 7.

Figs. 6 and 7.—Variation of composition with oxidation weight-gain at various temperatures. (° C.).

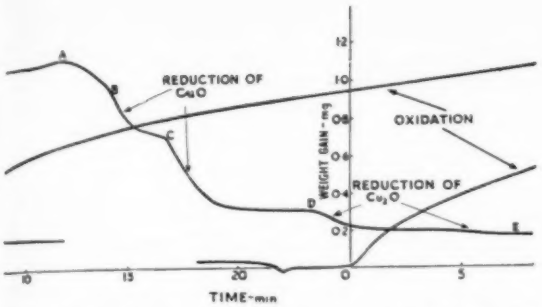

Fig. 8.—Oxidation at 420° C. and reduction of film after cooling in nitrogen to 270° C. (Specimen area, 5·01 sq. cm.).

The Effect of Cooling to Low Temperatures on Film Composition

A limited amount of work was done to try and determine the effect of cooling from the oxidation temperature on composition. It appears that the net effect of cooling scales formed in the region of 750° C. is to cause an increase in CuO content, even during cooling in O.F. nitrogen (see Table V).

Between 520° C. and 370° C., slow cooling appears to lead to a reduction in the CuO content of the scales. Here the CuO content is initially high (85–100%), and slow cooling in nitrogen probably permits outward diffusion of Cu^+ ions, which reduce part of the outer CuO layer to Cu_2O. Thus, scales formed at 520° C. with weight gains of the order of 0·45–0·49 mg./sq. cm. will initially contain about 85% CuO. On cooling, the resultant scale will contain only about 50% CuO, when reduced at 270°C.

Scales formed at 420° C. and reduced at 270° C. have their CuO content reduced from about 100% to 60–70% Likewise, scales formed at 370° C. are reduced in CuO content from 93% to 83%. Here, however, the decrease is not so great, probably due to the slow diffusion rate at the lower temperature.

These results suggest that the high temperature scales (formed at 750° C.) go through two stages during cooling, viz., an oxidation stage between 750 and 500° C., and a reduction stage between 500 and 270° C., resulting in a net oxidation. The cooling rates normally used in oxidation research are much faster, and the atmospheres are generally more oxidising than in this work, but the results should indicate the direction in which the changes are likely to take place.

TABLE V.—CHANGES IN SCALE COMPOSITION ON COOLING.

No.	Temperature ° C.		Cooling Time in Nitrogen (min.)	Oxidation Wt. Gain (mg./sq. cm.)	CuO (%)
	Oxidation	Reduction			
—*	750	750	nil.	1·93	12
118	750	270	40	1·93	38
120	520	520	nil.	0·49	85
114	520	280	26	0·46	48
112	520	270	28	0·45	50
121	420	420	nil.	0·036	97
107	420	270	21	0·23	67
111	420	270	17	0·20	63
121A	370	370	nil.	0·23	93
117	370	270	25	0·20	83

* Interpolated from Fig. 5.

Reduction at 270° C., after oxidation at 420 and 370° C. resulted in a peculiar type of reduction curve with three stages (see Fig. 8). The first slope (*AB*) is the induction or nucleation stage, which is visible in all reduction curves, but normally of shorter duration. Considering the rapid rates obtained, it would seem that the stages *BC* and *CD* both relate to the reduction of CuO. The first stage (*BC*) relates to that of a fairly compact layer, and the second more rapid reduction (*CD*) to a more pervious inner layer. The slow reduction represented by *DE* would relate to the reduction of Cu_2O. The figures given in Table V are based on this assumption.

The Rate of Reduction of CuO in Hydrogen-Nitrogen Mixtures

The rates of reduction of CuO were calculated from the linear portions of the reduction curves, such as those shown in Figs. 3 and 4. The results are shown in Fig. 9, where the logarithm of the reduction rate is plotted against the reciprocal of the absolute temperature to obtain the apparent activation energy from the Arrhenius equation. Due to the exceedingly high rates of reduction at high temperatures in conjunction with a time scale of 0·66 in./min., great accuracy cannot be expected. At 270° C. an accuracy of ± 7% can be obtained.

The effect of varying the partial pressure of hydrogen on the reduction rate of CuO was determined at 320° C. and the results are given in Fig. 10. Reduction rates at

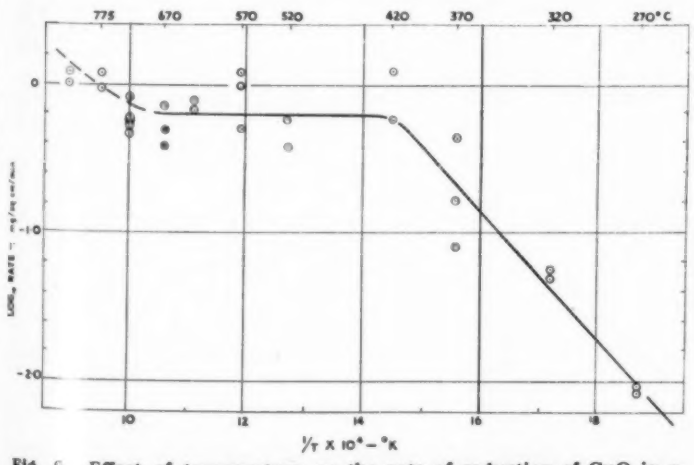

Fig. 9.—Effect of temperature on the rate of reduction of CuO in a dry hydrogen-nitrogen atmosphere. (Hydrogen pressure, 90 mm. Hg.).

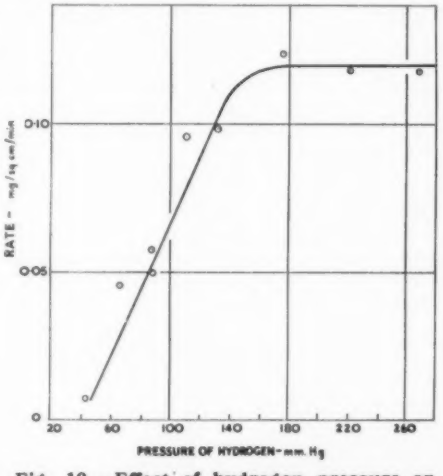

Fig. 10.—Effect of hydrogen pressure on reduction rate of CuO at 320° C.

670° C. tended to confirm the results at 370° C., but there was a great deal of scatter in the results for low partial pressures of hydrogen.

Discussion of Results

The results for the variation in composition with oxidation temperature agree fairly well with those of Valensi and others at temperatures of 500° C. and above. Therefore, they show that, at high temperatures, exfoliation and phase changes during cooling at normal fast rates affect the composition very little, and that the practice of taking the actual film composition as the mean between that of the exfoliated scale and that given by the lightly polished specimen gives a good approximation to the actual composition at the oxidation temperature.

Valensi's theory[1] on the formation of oxide films on copper postulates that at high temperatures the rate-determining reaction is :—

$$2Cu + \tfrac{1}{2}O_2 \longrightarrow Cu_2O.$$

This reaction can be made to proceed exclusively below the dissociation pressure of CuO, which is 150 mm. at 1025° C.

At low temperatures, the rate determining reaction, according to Valensi should be :—

$$Cu_2O + \tfrac{1}{2}O_2 \longrightarrow 2CuO.$$

Valensi was able to show that at 300° C. the oxide film contained about 95% of CuO. The boundary between the two processes is in the region of 500–600° C., in which range the film contains about 50% of each oxide. The composition of the films should be directly related to the oxidation temperature as shown in Table I.

The main difficulty was that the theory demanded 100% CuO in the films formed at low temperatures, whereas previous experimental work had shown that quite large amounts of Cu_2O were present in low temperature films. Valensi claimed that the reason for this difference was due to several factors, one being the effect of dissolved gases such as carbon dioxide, carbon monoxide and hydrogen in the tough-pitch copper which had been mainly used in the early work. Valensi considered that the CuO film was partly reduced to Cu_2O by hydrogen during oxidation. Non-reducing gases such as carbon dioxide and water vapour which might have been produced during oxidation were thought to produce blistering, which would also reduce the CuO content of the film.

Another factor which may have been responsible was the presence of a pre-existing film formed at room temperature, which early investigators had not removed. Since the copper used in this investigation was melted and heat-treated in vacuo, and the pre-existing film was removed by reduction in hydrogen, the possible effect of most of these factors should have been eliminated. There only remains the possible solution of hydrogen during the reduction period, and the effect of nitrogen in the oxidising atmosphere. Any hydrogen dissolved due to this cause would be rapidly released during oxidation, but its slower release at lower temperatures might be the cause of the initially low CuO content seen in films formed at 270° C (Fig. 7).

The effect of using oxygen instead of air at 320° C. has been to reduce the CuO content of the films. Thus, the use of air instead of oxygen in this work does not appear to be the reason for the difference in composition between Valensi's results and those given here at 370 and 320° C.

The main disagreement, i.e., the reduction in the CuO content with time, which is apparent in the majority of the curves, must be explained by a mechanism which holds good for both high and low temperature oxidation.

Valensi explained the presence of Cu_2O in films formed below 300° C. as being due to the speed of the reaction :—

$$Cu_2O + \tfrac{1}{2}O_2 \longrightarrow 2CuO,$$

being much reduced by the slow formation of nuclei of CuO. It seems more probable that oxidation starts by the formation of nuclei of Cu_2O, which are rapidly oxidised to CuO before forming a coherent film. Once a coherent film is formed, access of oxygen is lessened and reduction by Cu^+ ions from the metal itself becomes possible, thus reducing the CuO content to a value where the proportions of Cu_2O and CuO remain constant. The resulting curve would be of the type shown in Fig. 11.

At very low temperatures i.e., below 270° C., the reaction never gets beyond the first stage of increasing CuO content due to the low diffusion rate of Cu^+ ions. At high temperatures the first stage is of too short duration to be observed. The results obtained by Gulbransen and McMillan,[5] and by Bouillon[6] agree with this hypothesis. The electron diffraction results of Dankov and Ignatov[2] agree in principle, but they find that the CuO content decreases after 25 minutes at 200° C., whereas in this work at 270° C. (Fig. 7) it is still increasing after many hours.

The effect of using pure oxygen instead of air at 320° C. is to reduce the CuO content of the films. This seems to be due to the formation of blisters, which reduce the supply of Cu^+ ions. Blistering, however, is a process which accompanies the formation of all films formed in dry air over the temperature range 200 to 700° C., according to previous work,[10] but the spasmodic occurrence of this process may be responsible for the fact that the results at 520° C. do not conform with the trend apparent at temperatures of 320, 370, 620° C. and upwards.

The results obtained on the rate of reduction of CuO in hydrogen-nitrogen mixture throw some light on the mechanism of reduction of copper oxides. The first step will be the reaction :—

$$CuO + H_2 \longrightarrow Cu + H_2O$$

at the oxygen-CuO interface, which is apparently the rate-controlling step below a pressure of 140 mm. Hg of hydrogen. The activation energy of this reaction is about 16 K-cal./mole. The result will be the formation of metallic nuclei and the diffusion of Cu^+ ions towards them. Since the diffusion rate of Cu^+ in CuO must be

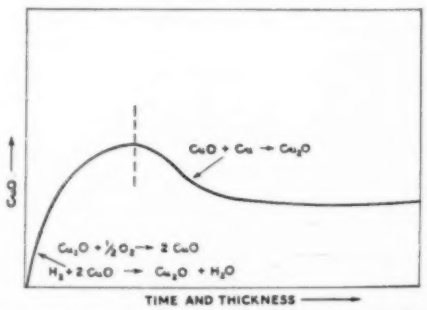

Fig. 11.—Probable change of composition in copper oxide films on copper (diagrammatic).

very low, the number of nuclei will be great and a thin film will soon be formed. The volume of this film will be some 37% less than the CuO from which it formed, and rifts will occur which will permit the inward movement of hydrogen to a fresh reaction surface, and the outward movement of water vapour. At pressures exceeding 140 mm. of Hg, it appears that the rate controlling step must be a diffusion process, probably that of Cu in CuO.

At higher temperatures than 420° C., sintering must be taking place on a large scale and reducing the area of the rifts. Sintering cannot go to completion, however, since the pressure of water vapour on the inside surface of the sintered layer will be continually creating rifts. It appears that over the temperature range 420–700° C., there is a balance between the increase of reaction rate with temperature and the increase of sintering. Fig. 9 shows a tendency for the reduction rate to rise again at temperatures above 700° C.

Conclusions

(1) The CuO content of scales formed on high-purity copper in dry air increases with reduction in temperature from 7% at 850° C. to about 100% at 420° C.
(2) For the majority of temperatures, the CuO content was found to decrease to a constant value, depending on temperature, as the film increased in thickness.
(3) At temperatures where the CuO content decreased with thickness, the lower limit of CuO content was reached in the thickness range corresponding to an oxygen weight-gain of 0·5 to 1·5 mg./sq. cm.
(4) The rate of reduction of the CuO layer of the scale increases with temperature from 270° C. (the lowest temperature investigated) to 420° C. It is reasonably constant between 420 and 720° C., indicating that sintering is taking place during reduction.
(5) The activation energy for the reduction of CuO between 420 and 270° C. is approximately 16 K-cal./mole.
(6) The rate of reduction of CuO at 320° C. increases linearly with the hydrogen partial pressure up to 140 mm. Hg. Above this pressure, the reduction rate shows no variation with pressure up to 270 mm.
(7) Above 420° C., reduction of CuO is mainly linear, that of Cu_2O mainly parabolic.

Acknowledgment

Thanks are due to The British Non-Ferrous Metals Research Association for the supply of high purity copper used in this work.

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Redux in Fairey Delta 2

Design details of the Fairey Delta 2, which recently established a new world speed record of 1,132 m.p.h., have yet to be released. It is, however, of interest to learn that Redux synthetic resin adhesive of Aero Research, Ltd., is used extensively for metal-to-metal bonding on several main components of this aircraft.

Conference on Heat Treatment Practice

At this conference, organised by the Metallurgy (General) Division of B.I.S.R.A., to be held at Ashorne Hill, near Leamington Spa, on June 5th and 6th next, the Chairman will be Mr. E. W. Colbeck of Hadfields, Ltd., and the Vice-Chairman, Mr. W. C. Heselwood of United Steel Cos., Ltd.

The broad outline of the conference is as follows : the first session will be concerned with distortion and cracking problems, and papers will be delivered by Mr. F. D. Waterfall (I.C.I., Ltd.) and Mr. P. E. Clary (Ford Motor Co., Ltd.).

Session two, on heating for forging and treatment, will be introduced by a paper from Mr. O. Hirston (Brown-Firth Research Laboratories) on "The Principles of Equipment to Ensure Good Heat Flow in Furnace Charges." This will be followed by a paper on "Heat Flow in Large Forgings," by Dr. F. W. Jones, also of Brown-Firth Research Laboratories. Also presented at this session will be a paper by Mr. J. E. Russell (English Steel Corporation, Ltd.) on "Rapid Heating of Small Forgings."

The third and last session will be concerned with transformations. Mr. H. Allsop (Brown Bayley Steels, Ltd.) will give a paper on "Isothermal Transformation Diagrams," and Dr. W. Steven (The Mond Nickel Co., Ltd.) will conclude with a paper on "Continuous Cooling Transformation Diagrams."

Application forms and full details of the arrangements can be obtained from the organiser and secretary, Mr. J. R. Powell, of the British Iron and Steel Research Association, 11, Park Lane, London, W.1.

Mr. MacLeod to Open Production Exhibition

Mr. Iain MacLeod, Minister of Labour and National Service, will open the 1956 Production Exhibition to be held at Olympia from May 23rd–31st. Sir Leonard Lord, K.B.E., President of the Institution of Production Engineers, will be President of the exhibition. This, the second exhibition, now moves into the Grand Hall to allow more spacious planning and improved amenities. As before, it deals with the importance of industrial productivity to the country's economic progress.

The main sections of the exhibition will cover : scientific research ; training and education for management and employee ; work study ; standardisation ; manpower ; new methods of manufacture ; aids to production ; automation ; materials and metals ; design for production ; and trade and technical press.

Under these broad headings exhibitors will show how they make use of research, how their products can be used to speed production, or ways in which increased productivity has been achieved in their own works. It is, thus, a selective exhibition. Great care has been taken to ensure that this is not primarily a "trade show" ; nevertheless, exhibitors achieve highly successful results by providing technical information about their own methods or products. Special encouragement has been given to small firms to exhibit.

Extensive Use of Aluminium Cladding at the New Marchwood Power Station

General view from the east; from left to right are the workshop and stores, the boiler house, the turbine house, and the administration block.

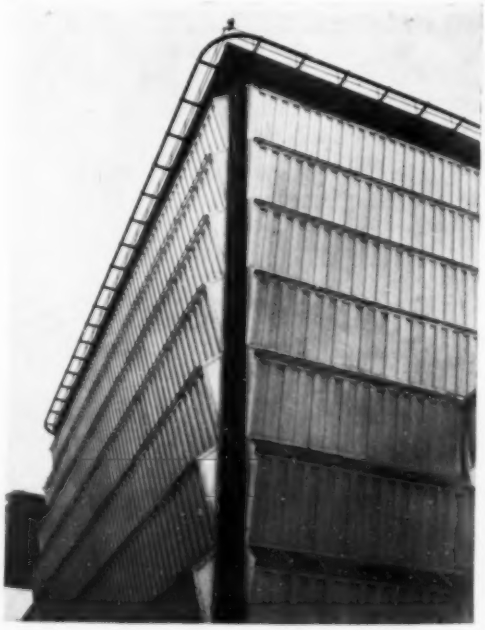
MARCHWOOD, on the west side of Southampton Water facing King George V Graving Dock, is the first electricity generating station in the south of England to have been conceived and constructed since the industry was brought completely under public ownership. One of over thirty new generating stations now under construction in various parts of the country, it first went on load at the end of 1955, but it will not reach its peak output until 1959, when the last of the eight 60,000 kW. hydrogen cooled turbo-alternators is installed. The station is only six miles from the recently completed oil refinery at Fawley, and is the first major power station in the country to be equipped to burn either 100% coal or 100% oil.

Over the last thirty years, electricity stations have changed very greatly in appearance. Their early undisguised industrial nature (which was criticised for being ugly, dirty and noisy) gave way with the growth of the industry to structures more worthy of note, designed by eminent architects. More recently there has been a withdrawal from brick structures, and some experiments have been made in the erection of " out-door " stations, where some of the engineering plant is quite uncovered.

Marchwood, in its outside appearance and its general architectural conception, is neither a monument in bricks nor unclothed engineering equipment, but uses as its protection from the weather the engineering materials of aluminium sheet and glass. Aluminium structural sections and glazing bars, and aluminium sheet in various forms have been used for the cladding above the 30 ft. concrete block walls, except for the patent glazing and a certain amount of vitreous enamelled infilling panels. Aluminium provides an infilling which is exceptionally light in weight (at Marchwood about 1 lb./sq. ft., as laid, not including the Asbestolux backing). It is easy to handle and fix, and, as no painting is required, except for exposed steelwork, maintenance costs are kept at a minimum.

Cladding of Buildings

Marchwood curtain walling required a completely different approach to interpret the architects' contemporary design, as it differs in almost every respect from the accepted standard of aluminium cladding. The supporting modules are of necessity much heavier, as they are designed to withstand a wind pressure of 27 lb./sq. ft. and to support reasonably heavy infill panels. Aygee, Ltd., who had recently completed a very large aluminium alloy contract at London Airport, developed the detail of the new scheme, bearing in mind the strict interpretation of the design, which called for many new extrusion dies and the application of an extensive variety of infilling media. The Research Department of the British Aluminium Co., Ltd., who supplied the aluminium

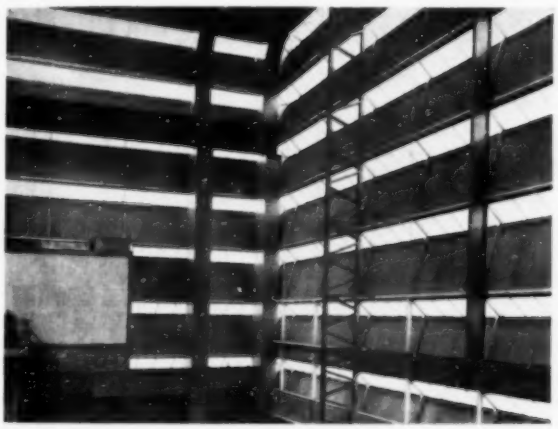


Eastern corner of the turbine house, showing details of the saw-tooth cladding.

alloy materials used, afforded invaluable assistance in this respect, and each new section was subjected to individual tests prior to the details being approved by the consultant engineers and architects.

Each structural member of the cladding was predesigned by Aygee, Ltd., for simplicity of erection, the special profile sheets backed with fire-resisting Asbestolux panels were in unit construction, and the whole scheme arranged to accommodate the varying infill panels, such as louvres, windows, enamelled sheets, plate and obscured glass, etc., without materially altering the connecting structure.

On the boiler house and turbine house the majority of the cladding is a special press-brake-formed 18 s.w.g. corrugated sheet, the profile of which can clearly be seen in the illustrations. The 2 in. deep rectangular corrugations are $9\frac{3}{4}$ in. wide and the pattern repeats itself every $19\frac{1}{2}$ in. On the end walls and the long face of the turbine house, this sheet forms a saw tooth pattern with the



Inside the turbine house, showing the uniform illumination.

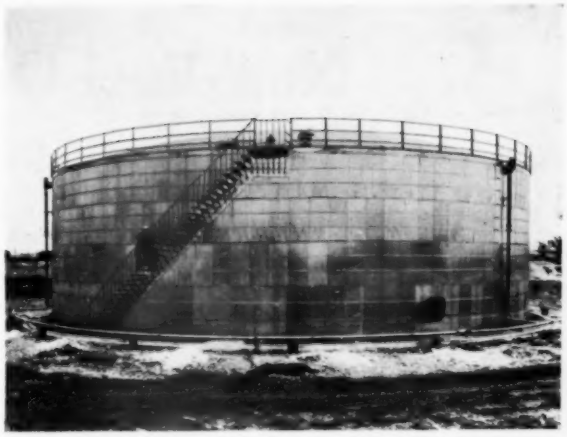
glazing; otherwise, it is applied vertically with a 2 in. side lap, the sheets being held at head and tail in aluminium extrusions.

Elsewhere, on the workshop and stores, the auxiliary boiler house, and the cooling water pump house, 18 s.w.g. standard Rigidal Industrial Trough T corrugated aluminium sheeting has been used in the same way, with a one-corrugation side lap, and, on the auxiliary boiler house, a 6 in. end lap. This type of sheet is also used extensively for the roof and side sheeting of the coal conveyors, and for the sides of the junction towers, where it is fitted in conjunction with patent glazing in extruded aluminium sections; most of the flashings to the coal conveyors are purpose-made to fit the corrugated sheet.

The fixing of this cladding is in general by Oakley clips and bolts, by ordinary hook bolts, or by plain bolts direct to the steelwork. Most of the wall cladding to the main buildings is lined with $\frac{1}{2}$ inch Asbestolux, Gyproc aluminium-foil-faced plaster board being used for lining the workshop and stores building.

Oil Fuel Storage Tanks and Other Applications

Marchwood is the first major power station to be equipped to work completely either with coal or oil, and provision is made for storing 10,000 tons of oil fuel in



One of the oil fuel storage tanks, showing the Rigidal covering of the insulation.

three tanks, each 88 ft. in diameter and 25 ft. high. Since the oil has to be maintained at a temperature of 123° F., so that it will flow freely through the pipelines, the tanks are insulated with 2 in. Rocksil medium density slabs. Weather protection is provided by 22 s.w.g. Rigidal 3 in. pitch corrugated aluminium sheeting, the total area covered being nearly 21,000 sq. ft. (5 tons).

Briggs aluminium decking has been used for the roof of the power house, as well as for some of the ancillary buildings; 18 s.w.g. Rigidal 3 in. pitch corrugated aluminium sheeting forms part of the facia to the turbine house; ($\frac{3}{16}$ in. aluminium solid fluted matting sheet is used for covers to heating pipe ducts in the administration block; preformed aluminium flashings and weatherings (16 and 18 s.w.g.) are used extensively; aluminium is also used for some partition framing and doors in the administration block.

Materials

The metal used throughout is BA Commercial Purity (99%) aluminium (S1C) for flashings and duct covers; BA.60 alloy (NS3) for all other sheet; and BA.24 alloy (HE9) for extrusions and glazing bars.

Altogether, the boiler house, auxiliary boiler house, power house and ancillary buildings have used about 56 tons of aluminium extrusions, glazing bars, flashings, and matting sheet, and about 86,000 sq. ft. (25 tons) of aluminium cladding sheet in various corrugated forms.

Full Production at Alcan

OFFICIALS of Aluminium Co. of Canada, Ltd., the principal subsidiary of Aluminium, Ltd., report that full production is being resumed in Alcan's Quebec smelters. The spring break-up is under way in the Northern watershed and is replenishing the reservoirs of the Company's hydro-electric system. In statements released last December and January, the Company announced that the drought of the summer of 1955 had reduced its water storage reservoirs below their normal level, and power output would be decreased during the winter months. The power shortage forced the curtailment of aluminium production from full levels at the Arvida, Isle Maligne and Shawinigan Falls smelters.

New Fuel Oil Applications

Improvements in oil burners, together with improved techniques, have made possible some interesting new industrial applications of oil firing. These recent developments were described in a paper presented to the Institute of Fuel on Wednesday, 4th April, 1956, by Mr. T. Chippindale, A.M.I.Mech.E., M.Inst.F., Assistant Fuel Oil Manager, Shell-Mex and B.P. Ltd. A slightly abridged version of Mr. Chippindale's paper is presented here.

THE industrial use of oil fuel in the U.K. has increased very considerably during the last few years. In 1938, the last complete year before World War II, the consumption was 1,425,700 tons ; in the coal crisis year of 1947 it was 3,498,800 tons ; whilst in 1955, it had grown to about 7¾ million tons, excluding the refineries' own consumption of about 2,000,000 tons.

The biggest increase in the use of oil fuel for any single application has been for open hearth steel melting furnaces. It was not until the end of 1945 that oil fuel was first used for that purpose, but it is now being used at the rate of nearly a million tons a year. The increased use for other applications has not been so rapid, and has continued on the lines of earlier development. The largest end uses are for steam raising and space heating, marine craft, gas making, reheating furnaces in steel works, and metallurgical furnaces.

To meet the country's energy requirements it is expected that the industrial use of fuel oil will have to be increased to about 22,000,000 tons by 1960. The Central Electricity Authority's programme will require about 6,000,000 tons, and no doubt considerable quantities will be used for gas-making. A large part of the remainder will be used for steam raising, with expansion in the other big tonnage uses following the lines of well-established custom.

There has, however, been considerable interest and development in a wide range of smaller applications. Improvement in oil burners, together with improved techniques, have made possible interesting new industrial applications, some of which will now be described.

Self-Proportioning Burners

A number of self-proportioning burners of the low pressure air type have been developed. These burners are supplied with all the air required for combustion, and are capable of maintaining a constant air : oil ratio over a turn-down range of about 5 : 1. They are operated by a single control lever which ensures that the air is reduced in step with the reduction in oil flow. This is a big improvement because, whilst it is possible with other low pressure air burners to change the oil and air in proportion by the operation of two separate controls, it is, unfortunately, an all too common practice to vary the oil flow only and leave the air flow unchanged. It is possible to couple the individual control levers of several burners together and operate them from one or more central control points. The application of automatic control has thus been made very much easier, and in a heat treatment furnace fitted with ten burners, controlled in two zones and operated by pneumatic servo motors, the temperature control is of the programme type, controlling both rise and fall, as well as holding a constant temperature over a given period. The burners are designed for a turn-down of 5 : 1 but, as the low setting may be too high for certain parts of the cycle, it is further arranged that the burners may be automatically cut out altogether, for subsequent re-lighting from the gas pilots.

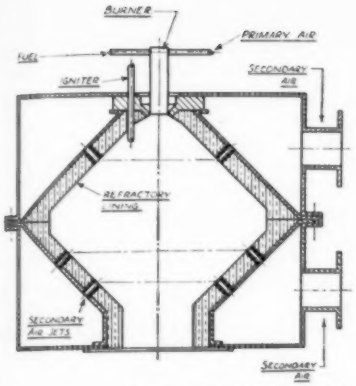
High Intensity Combustion

Until recently, it was normal practice to allow a combustion chamber volume of about 2½ cu. ft. for each gal./hr. of fuel oil, which is equivalent to a heat release of 70,000 B.Th.U./cu. ft./hr. Whilst this rating still applies for conventional oil burners and combustion chambers, a number of devices have been developed for high intensity combustion, which are capable of sustaining heat releases of at least 1,000,000 B.Th.U./cu. ft./hr. It is thus possible to complete combustion with very short flames : the issuing gases, combustion being complete, are not so highly radiant as the flames from normal oil burners.

The ability to obtain complete combustion in a short distance is used in many applications in which the products of combustion are diluted with cold air and used for drying processes. In such applications, it is essential that combustion be complete before the flame is cooled by the addition of the diluting air ; otherwise combustion will be arrested and unburned oil, smoke and carbon particles formed, resulting in contamination of the product being dried. It is sometimes convenient to use a high duty combustion chamber rather than the conventional combustion chamber of larger dimensions, but the additional power required to provide all the combustion air at a rather high pressure must also be taken into account.

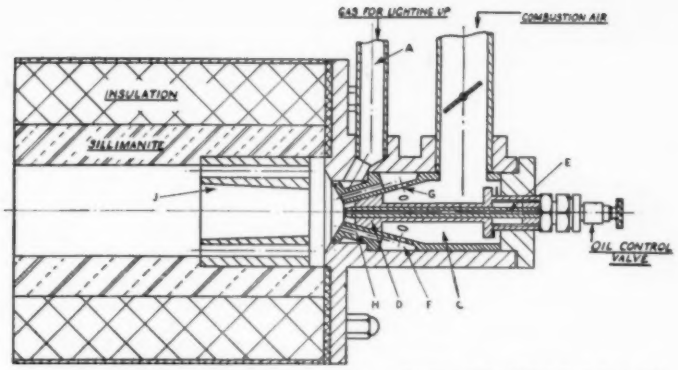
One type of high duty combustion chamber is produced in diameters from 18 in. to 5 ft., the length being equal to the diameter. The 5 ft. diameter chamber will release some 20,000,000 B.Th.U./hr. Due to the internal design of the atomiser, and of the secondary air entry, the exhaust products can be accurately controlled in temperature and composition, both above and below stoichiometric mixtures. Atomising air is required at 15 lb./sq. in. gauge, secondary air at 28 in. w.g. and oil at 5 lb./sq. in. gauge and above. These pressures must be increased to the extent of the pressure set up in the combustion chamber.

Another high heat release air-cooled combustion device, known as a " combustor " or " can," has been developed from the combustion chambers used for aircraft gas turbine engines. Units can be designed for minimum fuel flows of 3 gal./hr. and the upper limit of the combustor is at present 125 gal./hr. (20,000,000 B.Th.U.). The unit comprises a rigid cylindrical mild steel outer casing, with an integral mounting flange approximately midway in its length. The slotted part of the outer casing, which extends beyond the mounting flange, projects into the air supply header. Mounted concen-



Courtesy of Urquharts (1926) Ltd.

Fig. 1. Section through Urquhart high intensity combustion chamber.



Courtesy of David Etchells & Sons, Ltd.

Fig. 2. Section through Etchells No. 1 burner.

trically within the outer casing is a stainless steel radiation liner, Nimonic flame tube and swirler assembly. The burner is axially located in the swirler bore. Combustion air enters the outer casing and passes into the annulus between the outer casing and the flame tube through the entry slots. The air supply is spit into a feed to the swirler and a feed to the flame tube. This promotes the necessary air and fuel flow pattern to ensure rapid combustion of the fuel. In one particular unit, the maximum flame length at 23 gal./hr. and 18 : 1 air : fuel ratio, is about 12 in. beyond the flame tube discharge. Refractory lined combustors are required for use with residual fuel oils. In one application of this type of combustor, six are arranged to fire into an electric arc furnace to pre-melt the metal, the refining being then carried out electrically.

Still another high intensity burner as shown in Fig. 2 has been developed for use on rotary pin-heating furnaces, and for bolt-making, bar-heating and drop stamp furnaces. It has also been applied to galvanising baths and other types of furnace. The burner uses air at a pressure of 8–22 in. w.g., and an important feature is that the air control varies the oil throughput proportionately. Small burners have a turn-down range of 2 : 1, but with the larger sizes the range is 5 : 1.

Oil is supplied to the burner from a constant level float chamber through the tube marked *E*. Air is supplied through a butterfly valve and enters the venturi block marked *C*, some of it passing through the swirl cone *D*, which gives a small swirl to initiate atomisation. The remainder of the air enters the annular space *F* at the back of the venturi block through holes *G* and joins the flame through holes *H*. The refractory convertor block *J* is provided with eight $\frac{3}{8}$ in. diameter holes, as indicated. A pressure gradient of the order of $1\frac{1}{2}$–2 in. w.g. is created across the length of the block, and this causes some of the products of combustion to recirculate through these holes. This circulation of hot gases raises the temperature of the convertor block and assists early combustion.

The function of the tube marked *A* is to provide town's gas or propane for starting up the burner. Gas and air are supplied, and in about three to four minutes the gas flame raises the burner nose to a temperature at which the oil supply may be started. It is only necessary to turn off the gas supply when, with the oil valve open, oil will be induced from the constant level float chamber due to the partial vacuum at the burner nose, which had been broken by the gas supply.

It is possible to obtain smokeless combustion with no excess air, and steel can be heated to working temperature with the production of a minimum amount of scale.

Radiant Tubes

Radiant tubes are usually gas-fired, but oil-fired radiant tubes known as Jetubes have been successfully developed. A high combustion chamber temperature is maintained to ensure complete combustion of the gas oil, and the lower working temperature level required in the tube is obtained by diluting the flame by means of the recirculation of products of combustion. A small concentrated combustion chamber in the form of an alloy tube, thinly lined with refractory and having a jet type orifice, is employed. The heat release in the combustion chamber is in excess of 1,000,000 B.Th.U./cu. ft./hr., and the high temperature zone is confined to the combustion chamber. The high velocity stream of completely burned products of combustion issuing from the orifice provides the energy required to cause recirculation in the circuit of the O-type radiant tube, where the mass flow is increased some 5 to 8 times, and this promotes a high rate of heat transfer and ensures uniformity of radiation from each unit area of the element, and precludes the formation of hot spots—the common cause of failure of radiant tubes.

In the application of a series of Jetube heating elements to a pot type gas carburising furnace, the latter is hermetically sealed to retain the carburising gas and to prevent the infiltration of air. The furnace atmosphere is produced from burnt town's gas or burnt liquid petroleum gas (which is being used to an increasing extent because of its consistent quality) from which all oxidising and decarburising agents have been removed. An alloy steel cylinder surrounds the charge, beneath which a centrifugal fan is located, so that in operation the furnace atmosphere is circulated around the annulus between the alloy cylinder and radiant elements and through the load to ensure even contact of the gas with the pieces to be treated. When the load has reached the required temperature the carburising medium in the form of liquid petroleum gas is added to the carrier gas stream. In another and larger installation, 90 oil-fired Jetube radiants of the double O-type are used as heat exchangers for heating the process gas.

A similar jet type of burner has been used for firing an indirect heater for heating air for the hot blast to cupolas and process air for wind tunnels. Gas oil is burned in the combustion chamber with a heat release of over 1,000,000 B.Th.U./cu. ft./hr. and the high velocity jet effect at the burner orifice causes many recirculations of the products of combustion over the heat exchange bank of tubes within the refractory lined casing. Special features in the design lower the waste gas temperature to 120/150° C., and test efficiencies of 86% are regularly maintained. A typical heater is capable of heating 2,500 cu. ft./min. of air to 300° C. or, alternatively, 1,700 cu. ft./min. to 500° C., for the same fuel consumption.

A modified type of radiant tube has been applied to a continuous conveyor type of furnace for firing vitreous enamel on both sheet iron and cast iron. Combustion of the 200 seconds fuel oil occurs in an enclosed tubular system of refractory construction within the actual heating chamber, so that excessive heat losses due to high temperature walls and external flues are eliminated. Each heating element is so constructed as to allow the atmosphere of the furnace to circulate freely around it, thus taking advantage of the large radiation surface provided. The arrangement of the tubular heating elements into which the burners are fired is across the base of the working chamber, rising vertically on the opposite side and then returning vertically downwards to discharge into a collecting flue. Adjacent heating elements are fired from opposite sides of the furnace, thus compensating for any slight heat gradient and giving uniformity of heating. The waste gas collecting flues are continued from the heating chamber, through to the inlet end of the preheating chamber, thus affording sensible heat to the incoming cold load before passing the gases to the recuperator system.

Small Capacity Burners

The difficulty of achieving an even heat distribution in a large furnace has been solved in some cases by the use of a large number of small burners. The use of a medium pressure air burner of low capacity which, when fitted with a forced secondary air casing, enabled a turn-down range of up to 8 : 1 to be obtained, was the basis of the design of a portable cover type of furnace for annealing 240 tons of tinplate coils to a temperature of 680–720° C., depending on the purpose for which the tinplate is required. The base, 28 ft. 6 in × 17 ft. 6 in. overall, has eight annular hearth plates in two rows of four. A central row of three exhaust ports conducts the products of combustion to the flues in the basement. The coils of 4 ft. 6 in. maximum diameter are loaded on the hearth plates up to a maximum height of 11 ft., with a convector plate between each coil. The stack of coils is covered by a protective inner cover to which a protective atmosphere is piped, and reaches the coils through an aperture in the hearths. It is circulated around the coils by means of a fan located just below the hole in the hearth plate. The furnace cover, which is lowered on top of the base, is 28 ft. 6 in. long × 19 ft. wide × 15 ft. 3 in. high, and has fourteen burners on each side and one at each end, making a total of thirty burners per furnace. The burners are automatically controlled on the high-low principle, the total maximum oil consumption rate being 80 gal./hr. and the minimum rate 10 gal./hr. The oil consumption is 6½ gal. or 11 therms per ton of coil annealed.

Immersion Heaters

Prototype immersion heaters of the Kemp tube type have recently been oil-fired. The immersion heaters are similar to those used for salt-baths and lead-baths for annealing and tempering, type metal furnaces, etc., and are installed in a tinpot used for producing tinplate. The oil burner is of the same type as that used for the coil annealing furnace. Oil is supplied at a pressure of 10 lb./sq. in. and atomising air at a pressure of 5 lb./sq. in. The secondary air, at a pressure of 5 in. w.g. is introduced at three points in order to give the shape of flame required by the tube. The design of the tube unit permits the recirculation of some products of combustion and produces a uniform temperature throughout the length of the heater.

Oil Gasifiers

There are over 100 applications on the Continent of the O.C.C.R. oil gasifier which was developed by the Office Central de Chauffe Rationelle. It consists of a small vertical cylindrical chamber, into the base of which oil and primary air tuyeres are introduced. These are arranged at the periphery in such a manner as to impart a swirling spiral motion to the mixture of oil and gas. The volume of primary air introduced is controlled in relation to the amount of fuel oil supplied to the gasifier. The pressure in the primary air ring main, from which the tuyeres are supplied, governs the supply of oil to the gasifier chamber. Oil is fed to the gasifier from a constant level tank situated above the equipment. The pressure in this tank is maintained at that prevailing in the primary air ring main, and this causes oil to be fed to the gasifier through a calibrated orifice to the oil-feed pipe, in direct proportion to the primary air pressure. The products of this gasification process leave the top of the gasifier through a refractory lined tube, and are fed to one or more burners for combustion with secondary air, in a furnace adjacent to the gasifier.

During operation, less than 1% of the oil gasified, depending on the nature of the fuel used, is deposited in the form of coke in the base of gasifier. The deposit takes only a few minutes to remove, and consequently does not cause any appreciable drop in furnace temperature. Radiation losses from the gasifier amount to only 1–2% so that the overall efficiency is about 97–98%.

The character of the gas made from the fuel oil depends mainly on the air : oil ratio. The higher this ratio, the lower the resultant calorific value of the gas and the higher the temperature of the products leaving the gasifier. With a lower air : oil ratio, the calorific value rises and the outlet temperature falls, but, due to the lower cracking efficiency, the amount of non-gasified suspended carbon increases. The final results of combustion are not, however, affected to any extent because the effective calorific value depends on three factors: (*a*) the calorific value of the gas ; (*b*) the calorific value of the suspended carbon ; and (*c*) the sensible heat.

O.C.C.R. gasifiers are made in varying capacities ranging from 6 to 250 gal./hr. The smallest would be about 3 ft. and the largest about 6 ft. in diameter. Under normal conditions the gasifier has a turn-down range of 4 : 1, but a greater turn-down can be achieved by means of special modifications to the tuyeres. Gasifiers have been installed on metal melting and reheating

[*continued on page* 221.

The Strain-Age Hardening of Mild Steel*

By B. B. Hundy, B.Sc., PhD., A.I.M.†

The effects of strain ageing on the mechanical properties of mild steel are reviewed, and a modification of the dislocation theory of strain ageing to cover the change in strength and ductility during ageing is discussed. A reduction in the nitrogen content (to below 0·002% say) would improve mild steel from the point of view of ductility, but it would still be subject to a pronounced return of the yield point on ageing.

WHEN mild steel is allowed to age after cold working, there is a gradual return of the yield point and a change in the ductility and strength: the ductility is reduced and the strength, as shown by the yield stress and ultimate tensile strength, is increased. The occurrence of all these phenomena may be conveniently referred to as "strain ageing" and the loss in ductility and increase in strength can be specifically referred to as "strain-age hardening."

These ageing effects are very important commercially in mild steel sheets that have been temper rolled for deep drawing. The return of the yield point can lead to the appearance of stretcher-strain markings on the pressing, and to other faults such as buckles and bad shape. The reduction in ductility due to strain-age hardening may also be most serious as, if the draw is deep, it may contribute to the occurrence of splits and breaks in the pressing. The yield point of aged material can be suppressed again by various forms of mechanical treatment such as roller levelling, but ductility, once lost, is never regained except by re-annealing.

This paper first reviews the effect of strain ageing on the mechanical properties of mild steel, and examines the various factors affecting the degree of strain-age hardening. The theory of strain ageing is then examined in some detail in an attempt to explain the various phenomena.

General Features of Strain Ageing

It is now generally known that the marked yield point of a rimming mild steel can be removed by plastically working the steel in a suitable manner. If, however, the worked steel is allowed to remain at room temperature, or above, there is a gradual change in its properties; the yield point returns, the tensile strength increases and the ductility decreases. The return of the yield point on ageing temper-rolled steel sheet (C, 0·048%; Mn, 0·28%; S, 0·020%; P, 0·013%; Ni, 0·04%; Cu, 0·07%; and N, 0·0037%), is shown by the autographic stress-strain curves given in Fig. 1 for sheet rolled 1·4% reduction. Fig. 2 shows the variation of the mechanical properties of this sheet as ageing proceeds. It can be seen that the yield stress and yield-point elongation increase continually from the commencement of ageing, while there is little change in the tensile strength or ductility

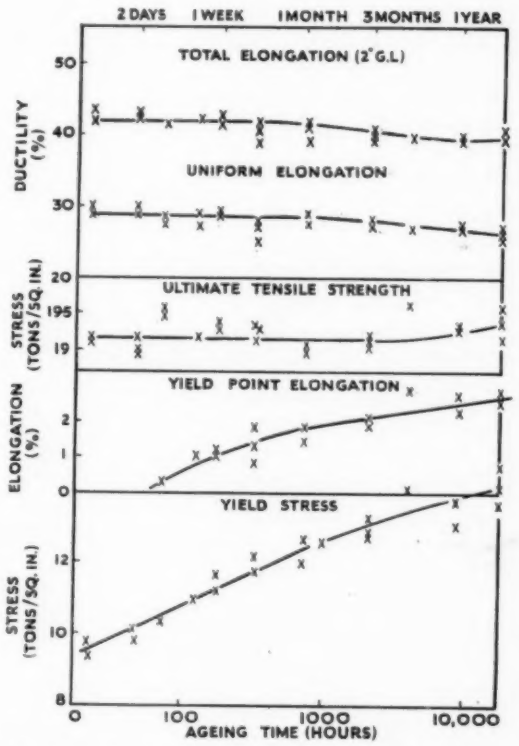


Fig. 2.—The effect of ageing on the properties of mild steel temper-rolled 1·4%.

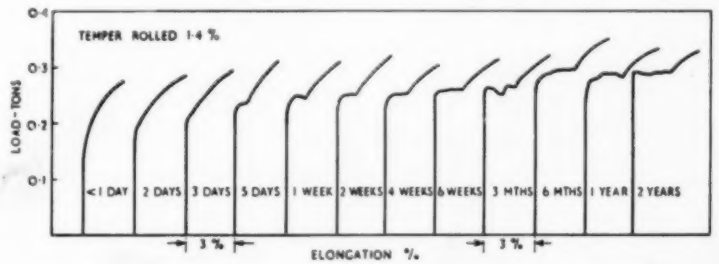


Fig. 1.—The effect of strain ageing on the initial part of the stress-strain curve of mild steel temper-rolled 1·4%.

* Paper MW/E/6/56 of the Sheet Metal Working Committee of the Mechanical Working Division of the British Iron and Steel Research Association. The views expressed are the author's and are not necessarily endorsed by the Committee as a body.

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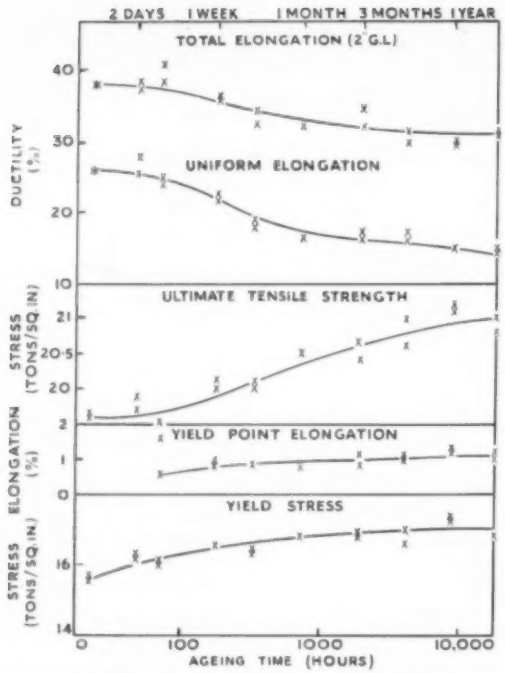


Fig. 3.—The effect of ageing on the properties of mild steel rolled 6·2%.

until the steel has been aged for about a week. Experiments have shown that the effect of ageing on these mechanical properties is dependent to some extent on the rolling reduction given to the steel, and Fig. 3 shows the effect of ageing on the properties of steel sheet rolled to a reduction of 6·2%. As in the case of the lightly rolled steel, there is a continual rise in the value of the yield stress and yield-point elongation from the start of ageing ; it seems, however, that the change in these properties is less than that found when the more lightly rolled steel was aged. On the other hand, the change in the tensile strength and ductility in the more heavily worked steel is much more pronounced than in the lightly worked specimens, and a change in these properties is noticeable from the early stages of ageing. Thus, it seems that the change in the yield stress and yield-point elongation becomes less as the rolling reduction is increased, while the change in the tensile strength and ductility becomes more marked. This conclusion is supported by a good deal of experimental evidence, and some typical results

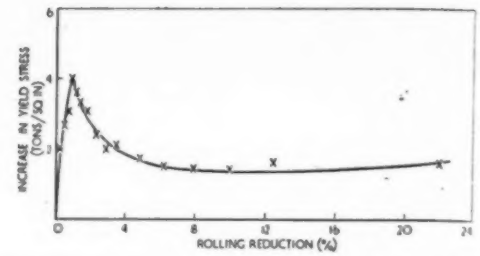


Fig. 4.—The effect of the degree of rolling on the rise in the yield stress due to ageing for 3 months after rolling.

showing the changes due to ageing sheets rolled to different reductions are presented in Figs. 4, 5, 6, and 7.

The magnitude of the rise in the yield stress on ageing (Fig. 4) decreases as the rolling reduction is increased until, at a reduction of about 6–8%, it reaches a fairly steady value : the smaller rise in the yield stress at very light rolling reductions is due to the fact that the original yield point of the annealed material was not completely eliminated by these amounts of rolling. Fig. 5 shows that the magnitude of the yield-point elongation returning on ageing is affected by the rolling reduction in a similar way to the yield stress : the marked effect of the rolling reduction in reducing the magnitude of the yield-point elongation returning on ageing has been explained in terms of the masking effect of the residual stresses induced in the sheet by the rolling process.[1] The main feature of the curves in Figs. 6 and 7 is that they show a maximum effect at a rolling reduction of about 12–15%, i.e., this steel shows the most marked strain-age hardening on ageing after cold working to strains around these values. Tests on sheets stretched in tension by various amounts have shown that results of this kind are not confined to rolled sheets, and other workers[2,3] have made similar studies which reveal that, although small differences in detail may be found, the behaviours described here can be regarded as typical.

Other tests have shown that the rate of return of the yield point in temper-rolled mild steel is not the same in the rolling direction as in a direction transverse to this. In lightly rolled sheets (see Fig. 8), the yield point returns more rapidly in the transverse direction than in the direction of rolling, while for higher rolling reductions (>3%) the converse behaviour is observed. This has been explained by reference to the masking action of macro- and micro-residual stresses on the yield point in the two directions.[4] On the other hand, it was found that the change in ductility or tensile strength on ageing was prac-

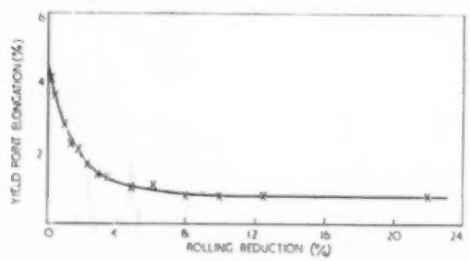


Fig. 5.—The effect of the degree of rolling on the yield point elongation due to ageing for 3 months after rolling.

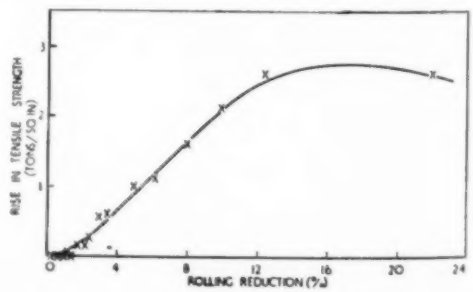


Fig. 6.—The effect of the degree of rolling on the rise in tensile strength due to ageing for 3 months after rolling.

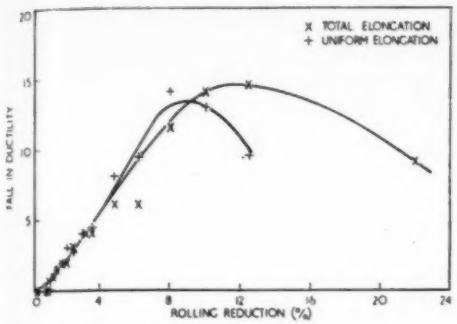


Fig. 7.—The effect of the degree of rolling on the fall in ductility due to ageing for 3 months after rolling.

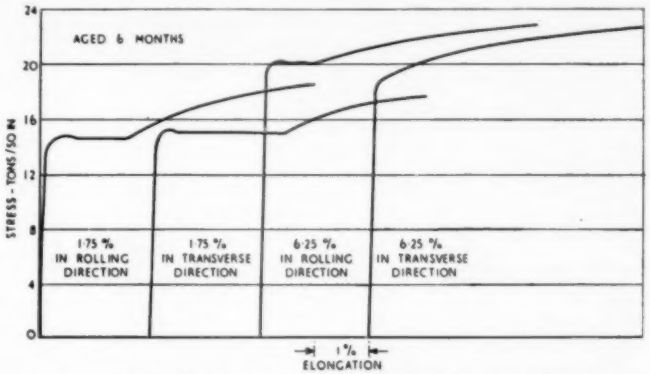

AGED 6 MONTHS
STRESS - TONS/SQ IN
1·75 % IN ROLLING DIRECTION
1·75 % IN TRANSVERSE DIRECTION
6·25 % IN ROLLING DIRECTION
6·25 % IN TRANSVERSE DIRECTION
1 % ELONGATION

Fig. 8.—The effect of the direction of testing on the shape of the stress-strain curve of temper-rolled steel sheet aged for 6 months.

tically the same in both transverse and rolling directions. Fig. 9, for instance, shows the change in the ultimate tensile strength in the rolling and transverse directions after ageing for 12 months. The only slight difference observed in similar plots showing the change in ductility was that there was a very slight tendency for the fall in ductility on ageing to be greater in the transverse direction in the more heavily rolled sheets (7% reduction).

This summary suggests that there might almost be two processes taking place simultaneously, one affecting the yield properties and the other the fracture properties. Previous work,[5] however, has shown that the change in all these mechanical properties is governed by the diffusion of carbon and/or nitrogen through the ferrite, and the two processes are therefore probably connected.

The following general conclusions can now be drawn :—

(*i*) At low rolling reductions, the yield stress and yield-point elongation are affected by strain ageing to a much greater extent than the tensile strength and ductility. At higher rolling reductions, the converse seems to apply.

(*ii*) At all reductions, there is a continual rise in the yield stress from the start of ageing. The tensile strength and ductility are, however, not affected until a later stage in the ageing process, unless the rolling reductions are fairly heavy.

(*iii*) The maximum change in the yield point due to strain ageing is found at low rolling reductions, whilst for mild steels of normal analysis the maximum strain-age hardening effect is found at rolling reductions round about 10–15%.

(*iv*) The rate of return of the yield-point is different in the rolling and transverse directions, but there is no anisotropy in the effect of ageing on the ductility or tensile strength.

(*v*) There is sufficient evidence available to show that both the return of the yield point and the increase in tensile strength and loss of ductility on strain ageing are governed by the diffusion of carbon and/or nitrogen through the steel.

Theory of Strain-Age Hardening

The Effect of Ageing on the True Stress-Strain Curve

The results presented in the last section show that strain ageing gives rise to a general hardening of the steel, together with a fall in ductility. The exact form of this hardening is not certain, however, and it has not been shown that this hardening is the cause of the observed decrease in ductility. For these reasons it was decided to investigate the fundamental changes in the stress-strain curve, due to ageing, in more detail. Round, 0·564 in. diameter, mild steel test bars (C, 0·06% ; Mn, 0·38% ; S, 0·035% ; P, 0·017% ; Ni, 0·055% ; Cu, 0·08% ; and N, 0·003% ; B.I.S.R.A. Store of Steels Reference BC) were used for this, and the true stress-natural strain curves were determined using a hand micrometer with a hemispherical head to measure the strain at the smallest cross-section. Some specimens were strained to fracture, while others were interrupted by an ageing treatment after 10% strain. The results obtained are shown in Fig. 10.

It will be seen that ageing leads to a marked increase in the yield stress (the usual return of the yield-point), and to a general rise in the level of the stress-strain curve. In addition to these effects. the rate of work hardening during the early stages of straining after ageing is increased markedly. It is also noticeable that the total strain at fracture, i.e., that given by the reduction in area, is reduced by an ageing treatment.

The amount of uniform elongation is fixed by the relation between the rate of work hardening and the level of the stress-strain curve. Any process that raises the height of the stress-strain curve more than it affects the rate of work hardening will lead to a decrease in the uniform elongation, even though the load at the point at which necking commences (ultimate tensile strength) will be

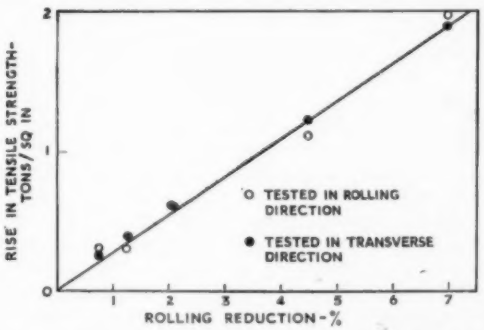


Fig. 9.—The effect of the direction of testing on the rise in tensile strength due to ageing for 12 months after rolling.

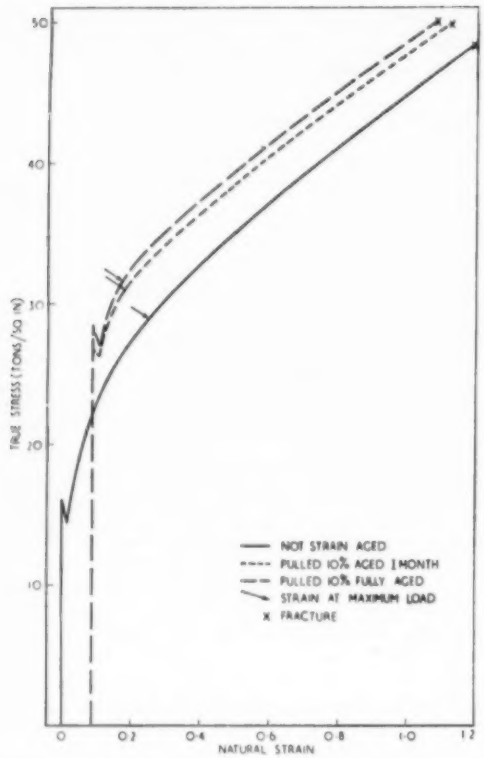


Fig. 10.—The effect of strain ageing on the true stress-strain curve for mild steel.

raised. The increased rate of work hardening due to strain ageing is only apparent in the early part of the stress-strain curve, so that, normally, ageing should give a decrease in the uniform elongation. This is the behaviour observed. The fall in the total elongation, of course, is a function both of the fall in the uniform elongation and of the decrease in the absolute ductility (the reduction in area at fracture) of the steel.

These results show that to explain the fall in ductility and increase in strength due to strain-ageing it is only necessary to explain the general rise in the level of the stress-strain curve. An explanation must therefore be sought in terms of an effect which strengthens and hardens the steel.

Dislocation Theory of Strain-Age Hardening

Many theories have been advanced at one time or another during the past forty years to explain the yield point in mild steel and the phenomenon of strain-ageing, but generally it has been found that most of these are not completely satisfactory, as they do not explain all the features associated with this phenomena.[6-10] Recently, however, Cottrell and his co-workers[11-16] have put forward a theory based on the concepts of crystal dislocations, which explains most of the phenomena associated with the yield point and strain-ageing. This theory, which is based on the idea that dislocations are bound in place by "atmospheres" of carbon and/or nitrogen atoms is supported by appreciable experimental evidence,[17, 18] and is now generally accepted by most workers. As the theory has already been described many times in the literature, no attempt will be made to do so here.

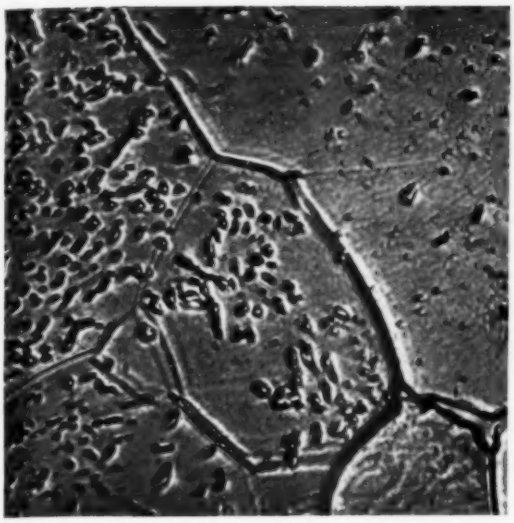
It is difficult, however, to see how this theory can explain the fall in ductility and increase in strength associated with strain ageing. Once the dislocations have been freed from their solute atom "atmospheres," these solute atoms should not affect the plastic properties so as to lead to an increase in strength. It is not possible to detect any fall in ductility on strain ageing in many non-ferrous alloys, even though there is a return of the yield point,[19, 20] and in these metals the dislocation theory probably provides the complete explanation of strain-ageing. It seems, however, that it must be modified in some way if it is to explain the fall in ductility and increase in strength during the ageing of strained mild steel, and a possible explanation of these effects in terms of the dislocation theory is as follows.

When, as is normal practice, mild steel is slowly cooled after annealing, carbon and nitrogen atoms form "atmospheres" around the dislocations in the iron lattice and at the grain boundaries; if the rate of cooling is very slow, a state of near-equilibrium is probably reached. Most of the remaining carbon and nitrogen is precipitated out of solution as iron carbides, nitrides and carbo-nitrides, while a small amount remains in solid solution in the iron. When the steel is cold worked, the dislocations are freed from their "atmospheres," and the number of dislocations increases by many times[16]. On ageing, the carbon and nitrogen atoms diffuse through the lattice to form "atmospheres" around both the old and the new dislocations. In its original form, the dislocation theory assumed that only one or two solute atoms would be attracted to each dislocation, but if it is assumed that many more, up to 50 in number, diffuse to each dislocation, then the increase in strength due to strain-ageing can be explained on a sub-precipitation hardening basis.*

Bilby and Leak[21] have suggested that any solute atoms in excess of 1 or 2 per dislocation that are attracted to the dislocation will diffuse rapidly along the dislocation line until they meet a barrier, when they will form a very tiny precipitate; it is very probable that such a barrier could be caused by the intersection of two or more dislocation lines. These small precipitates then, although probably still too small to be visible even under an electron microscope, must have a precipitation hardening effect on the steel which will raise the general level of the stress-strain curve. Even when the dislocations are dragged away from their atmospheres by the plastic working, these tiny precipitates will remain, and will make the movement of dislocations more difficult, and will thus harden the steel. It is only when the steel is allowed to age again after straining that these aggregates of solute atoms will disperse through the iron lattice to form fresh atmospheres around the new dislocations and further tiny precipitates.

The extent of the hardening will depend on the size and spacing of these small sub-precipitates which are formed during ageing.[22] When steel is strained plastically, the dislocation density is markedly increased so that the spacing of the precipitates will be much closer and the hardening effect will be greater. The actual amount of strain in the specimen governs the dislocation density, and this explains why the strain-age hardening effect increases with the amount of strain. The size of the

* In effect this theory combines the dislocation theory with the earlier theory of Edwards, Phillips and Liu.



Reduced ¼ linear in reproduction.

(a) **Annealed basic Bessemer steel aged 1 hour at 200° C.**

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(b) **Annealed basic Bessemer steel aged 1 hour at 200° C., but cold worked before ageing.**

Fig. 11.—The effect of cold working on the precipitation of iron nitride in steel. ×1750

precipitate increases during the ageing process, as more solute atoms diffuse through to the dislocations and then along the dislocations to the precipitates, and this explains why the strain-age hardening effect increases with the time of ageing. The fact that strain-age hardening takes place much more rapidly in specimens rolled to higher reductions is easily explained when it is realised that fewer solute atoms have to diffuse to the dislocations to give a hardening effect when the dislocation density is high; the closer spacing of the precipitates gives an equal hardening effect with much smaller size precipitates. The reason why the strain-age hardening decreases again at reductions greater than about 12–16% is probably that, although the dislocation density is higher, there are not sufficient solute atoms available to form a full size stable sub-precipitate at all the available positions in the steel.

The hardening due to such a process would be roughly the same in all directions in the steel, and this then explains why there is no appreciable difference in the amount of strain-age hardening in the rolling and transverse directions in temper-rolled steel sheet, even though there is anisotropy in the rate of return of the yield point. As already pointed out, this latter feature can be explained on the basis of the masking action of residual stresses, and these are unaffected by the details of the actual strain ageing process.

There is a certain amout of evidence in the literature that dislocations can attract solute atoms to the extent indicated above. Harper[17] and Thomas and Leak[18] have studied the rates of strain-ageing in quenched mild-steel specimens by an internal friction method, and Dahl and Lücke[23] have made a similar study using a resistivity technique. Their calculations showed that from 10 to 100 solute atoms per atom plane were attracted to each dislocation, and they suggested that these should form some sort of precipitate at the dislocation. Thus, provided enough solute atoms are available, it seems that dislocations can attract them in the numbers envisaged in the theory put forward here, and they will tend to form small precipitates.

The Source of the Solute Atoms for Strain Ageing

The hypothesis put forward above requires that a large number of solute atoms be available to diffuse to the dislocations on ageing after straining to form the small sub-precipitates. It is necessary to determine, therefore, whether solute atoms in such numbers are in fact available in mild steel.

Steel strained 2–3% has a dislocation density of about 10^{10} dislocation lines per sq. in.* and it can be easily shown that 0·0005% of carbon or nitrogen is sufficient to supply about 5 solute atoms to each dislocation, which should be amply sufficient to give a hardening effect. Thus, ordinary mild steel containing about 0·05% carbon and 0·005% nitrogen contains ample solute atoms for a process such as that described above. This, however, assumes that all the carbon and nitrogen are in solid solution, and are available for diffusion to the dislocations. This will not normally be so; most of the carbon and nitrogen in annealed mild steel is precipitated out as carbides and nitrides; only a very small amount (10^{-7}% carbon and 10^{-5}% nitrogen) is retained in solid solution, and about 10^{-5}% is probably distributed around the dislocations in the annealed metal.

To provide sufficient solute atoms for strain ageing, let alone the strain-age hardening effect postulated above, it is necessary for the precipitated carbides and nitrides to redissolve in the ferrite. Williams and O'Neill,[24] using an electron microscope, have found that grain boundary films of carbide or nitride in mild steel are dissolved during ageing after cold work, and the work of Andrew and Trent[25] and Wilson[26] suggests that solute atoms such as carbon and nitrogen prefer to remain bound to dislocations in some way, rather than precipitate out as

* The figures for dislocation densities quoted in this paper are the most recent given in the literature. There is, however, still some doubt over the actual dislocation densities in metals and these figures may not be exactly correct.

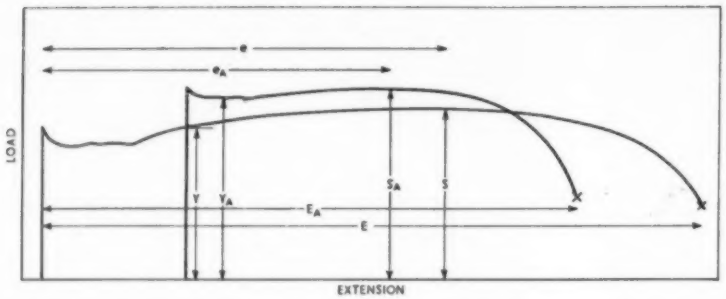

Fig. 12.—The effect of strain ageing on the load-extension curve for iron containing 0·0035% C. and 0·0025%N.

massive iron compounds. The photomicrographs given in Fig. 11 also confirm that massive precipitation of iron nitride needles can be prevented by deformation of the metal. It appears, therefore, that redissolution of precipitated particles can take place on ageing after cold working. The sequence of events is probably as follows: straining annealed mild steel results in the formation of many new dislocations, and, when the steel is aged, these attract solute atoms and remove them from solid solution, depleting the ferrite of solute atoms. To maintain a state of equilibrium, the precipitated carbides and nitrides tend to redissolve, and a quasi-steady state is set up, with the carbides and nitrides dissolving in the ferrite to give free carbon and nitrogen atoms, which move through the iron lattice to the dislocations, where they are removed from solution again. Carbon cannot be expected to play a very big part in the strain-ageing of slowly cooled steel, as the equilibrium solubility of carbon in ferrite is about 10^{-7}%, whilst that of nitrogen is about 10^{-5}%.[27] This suggests that, in slowly cooled steel containing both carbon and nitrogen, about 100 nitrogen atoms will be taking part in the ageing process for every one carbon atom. The insignificance of carbon in causing strain ageing is confirmed by the fact that non-ageing steel can be produced by stabilising only the nitrogen in an innocuous form;[28, 29] it is not necessary to stabilise the carbon at all.

Evidence for the Theory of Strain-Age Hardening

The theory put forward above can account for most of the phenomena associated with strain ageing that could not be explained by the the dislocation theory in its simple form, and the fact that theory can explain these features may be taken as helping to confirm its validity.

Further experimental evidence is needed, however, before the theory can be accepted completely. Unfortunately, it is almost impossible to obtain direct evidence that precipitation or sub-precipitation is occurring at dislocations and is causing the fall in ductility on strain ageing. The precipitates are too small to be distinguished clearly by a microscopic method, even if a high resolution electron microscope were used. Williams and O'Neill[24] did find, however, that the interior of mild steel grains showed a slightly mottled appearance after long periods of ageing, and they suggested that this might be due to some sort of precipitation.

If a mild steel specimen (especially one with a high nitrogen content) is deformed locally; aged at 250° C. and etched in acidic copper chloride solution, the plastically deformed areas etch up much darker than the undeformed regions.[30-32] This suggests that the plastically deformed regions must be in a different chemical state from the annealed region. This differential etching effect only occurs if the specimen is aged, and is not observed if the specimen is etched immediately after cold working. Ageing must, therefore, bring about some chemical change in the worked area, and the formation of very small precipitates at the relatively numerous dislocations in the worked region could be the cause of this.

The results of a number of investigations[2, 33, 34] show that straining after quenching mild steel can profoundly modify the quench ageing process, and can prevent massive precipitation from occurring. As the solute atoms are not retained in solid solution, it seems that they probably precipitate in very small groups, as suggested here.

According to the theory, the yield point in mild steel should begin to rise immediately after straining, but there should be no appreciable change in the ductility or strength until each dislocation has attracted a certain minimum number of solute atoms: the ductility and strength should not start to change until ageing has been continued for some time. This behaviour was observed at the lower rolling reductions in the tests described earlier (Fig. 2), and similar results have been obtained by Jones and Owen-Barnett.[35]

A final, and perhaps decisive, check on the theory would be given if it could be shown that, as the solute content of the steel is progressively reduced, the strain-age hardening effect (the change in ductility and strength) vanishes before the strain ageing effect (the return of the yield point). As the carbon and nitrogen content of steel is reduced, the number of solute atoms available to diffuse through the steel to the dislocations will decrease, so that eventually a point will be reached when there are insufficient atoms available to form even a tiny precipitate, and there will be no hardening effect. At this point, however, there should still be sufficient solute atoms to stabilise the dislocations in the strained steel giving a return of the yield point on strain ageing. As the solute content is decreased even more, a stage will be reached when there are enough solute atoms to anchor the dislocations in the annealed steel, but not the increased number formed on straining the metal; the steel will have an initial yield point but will not show any signs of strain ageing.

Experiments were therefore carried out to confirm that this was the behaviour actually observed. The steel used was of very high purity, so that the presence of any other solute atoms in the steel, besides carbon and nitrogen, would not affect the results. The batch composition of the steel was C, 0·0035%; N, 0·0025%; Si, 0·0025%; Mn, 0·004%; S, 0·005%; P, 0·001%; Ni, 0·010%; Cu, 0·006%; and Al, 0·001% (B.I.S.R.A.

Store of Steels Reference AH). Samples tested in the annealed condition showed a pronounced yield point return on ageing at 114° C. for 16 hours after straining 10%, together with a marked decrease in the ductility.

The type of stress-strain curves obtained are shown in Fig. 12. Strip tensile specimens of the steel were heated in a stream of wet hydrogen at 800° C. for various periods, so as to reduce the carbon and nitrogen contents. The specimens were then homogenised for 16 hours at 750° C. Some test pieces were pulled to fracture with no intermediate treatment, so as to obtain values for the unaged mechanical properties, and other comparable specimens were strained 10% in tension and were aged at 114° C., for 16 hours before continuing the test. The fall in ductility ($e-e_A$ and $E-E_A$), increase in tensile strength (S_A-S), and increase in the yield point (Y_A-Y)) due to strain ageing are plotted in Fig. 13 against the heating time in wet hydrogen. As the time in wet hydrogen increases (i.e., the carbon and nitrogen contents decrease) the steel behaves as predicted. After heating for about two hours, there is only a very small fall in ductility due to strain ageing, but there is still a very pronounced return of the yield point. As the time of heating in wet hydrogen is increased further, the next stage is reached when, after about 10 hours, no marked yield point returns on ageing. At this point, the steel still has an initial yield point and the heating would have to be continued for even longer times to eliminate this. Samples were taken from these specimens for chemical analysis of the carbon and nitrogen, and the figures obtained are shown in Fig. 13. It is practically impossible to obtain very accurate carbon and nitrogen contents when they are as low as in this work, so too much reliance should not be placed on these figures. They do, however, suggest that there is no fall in the ductility due to strain ageing when the carbon content is about 0·0018% and the nitrogen content is about 0·0008%. Strain ageing no longer occurs when the carbon is reduced to 0·0007% and the nitrogen to 0·0002%.

Further supporting evidence can also be found in the literature. Low and Gensamer[36] carried out similar decarburising (and denitriding) experiments on a number of commercial steels, and their results showed the same sequence of events as was observed in the present work. Figures taken from their work are shown in Table I.

Additional experiments on some aluminium stabilised deep-drawing steel sheets (C, 0·055%; Mn, 0·31%; S, 0·025%; P, 0·012%; and Al, 0·045%) provided further support for the theory. The excess of aluminium in this steel stabilises the nitrogen as aluminium nitride, and prevents it from taking part in the strain ageing process; only carbon atoms are available for this. This steel has a pronounced yield point in the annealed state, so that the dislocations are probably locked by carbon "atmospheres." The equilibrium solubility of carbon in ferrite at room temperature is very low (10^{-7}%[27]) so that when the yield point is removed by plastic deformation there can be very little redissolution of the carbides to supply additional carbon atoms for diffusion to the dislocations, so there will not be sufficient carbon atoms available to lock the dislocations and give a return of the yield point. If the ageing temperature after straining is raised above room temperature, however, the amount of carbon in solid solution is also raised, and there will be more tendency for the carbides to dissolve in the ferrite, making extra carbon atoms available to lock the dislocations. Thus, as the ageing temperature is raised, a point should be reached when the yield point returns on ageing but where there is no strain-age hardening. At still higher ageing temperatures, strain-age hardening should also be apparent. The results of some tests on the effect of ageing at different temperatures after stretching the aluminium-stabilised steel specimens 10% are shown in Fig. 14. It will be seen that ageing at temperatures in the range of 100°–220° C. gives a return of the yield point but no change in tensile strength and ductility; this only occurs when ageing is done at temperatures higher than 220° C.

All this evidence seems to support the theory outlined earlier, and it is probably reasonable to adopt this as a working hypothesis to explain the phenomena of strain-age hardening in mild steel.

TABLE I.—HEATING TIMES IN WET HYDROGEN TO ELIMINATE THE VARIOUS STRAIN AGEING PHENOMENA. (FROM LOW AND GENSAMER[36])

Steel	Time to Remove Initial Yield Point (hr.)	Time to Prevent Strain Ageing (hr.)	Time to Prevent a Fall in Ductility on Ageing (hr.)	Time to Prevent a Rise in the U.T.S. on Ageing (hr.)
T—3	2·8	2·2	1·9	1·8
Th—6	13	11	10	10
T—3	1½	1½	1	¾
T—4	2	1½	1½	1½

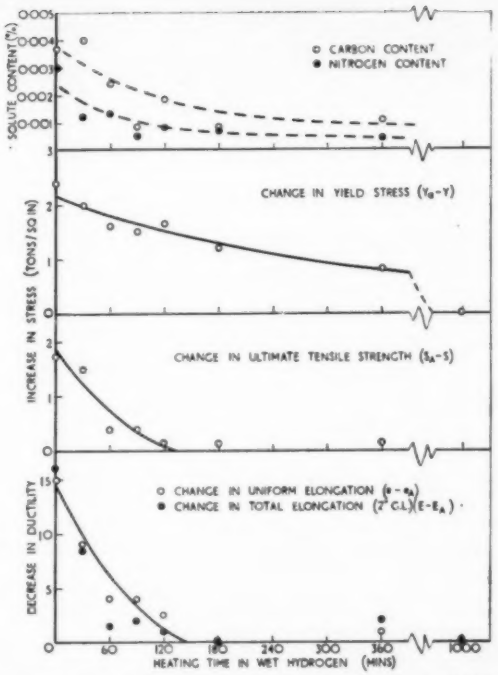

Fig. 13.—The effect of heating in wet hydrogen at 800°C. on the change in properties due to straining 10% and ageing fully.

Discussion

It is generally desirable to reduce any strain ageing effects in deep-drawing mild steel to a minimum, so as to avoid defects such as stretcher strains, buckles, splits and breaks. Roller levelling before pressing helps to minimise some of these defects, but cannot improve the fundamental loss in ductility due to ageing. It is proposed to examine the theory of strain-age hardening

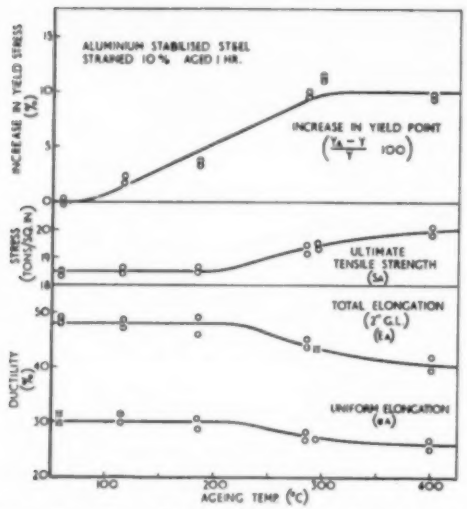

Fig. 14.—The effect of increasing the ageing temperature on the mechanical properties of stabilised mild steel after straining and ageing.

outlined here to see if it can suggest any methods of reducing the strain-age hardening effects.

The loss in ductility due to strain ageing becomes much more marked as the temper-rolling reduction is increased, and this suggests that this reduction should be kept as low as possible, and that any ancillary working operations such as levelling or coiling should be arranged so as to introduce as little cold work into the sheet as possible. Unfortunately, the yield-point elongation returns more rapidly as the rolling reduction is decreased, and this would give rise to very pronounced stretcher-strain markings on pressings made from this material. It is thus necessary to compromise between these two conflicting requirements, and choose a temper-rolling reduction that delays the return of the yield point for a reasonable time, but which does not give rise to a very pronounced strain-age hardening effect. These ageing effects could also be reduced if the rate of diffusion of solute atoms in ferrite could be reduced. Keeping the steel cool will achieve this, and the advantages of having cool steel stores in the press shops have already been pointed out.[5, 37]

The work of Snoek[38] and Low and Gensamer[36] has shown that a steel that is essentially free from carbon and nitrogen does not show either an initial yield point or strain ageing, and this is in accordance with the predictions of the dislocation theory. Generally, when the steel is cooled slowly, the solubility of carbon in ferrite is so low that it is only necessary to stabilise the nitrogen in an innocuous form to prevent strain ageing, and many thousands of tons of non-ageing steels are produced annually by adding a slight excess of aluminium to combine with the nitrogen. These steels, however, are killed, and the ingots have a relatively poor surface finish and require more conditioning; the steels are, therefore, more expensive than the normal rimming steels. Although, from a technical point of view, these aluminium-treated steels provide a solution to the strain ageing problem, economic considerations prevent their general use. It is, therefore, necessary to examine the usual methods of steel making to see if these could be improved so as to yield a rimming mild steel with less tendency to strain age. As has been pointed out earlier, it is only necessary to consider nitrogen in this respect. Any strain ageing due to carbon alone can be neglected.

If we assume that a dislocation can be locked in place by 1 or 2 solute atoms, then the weight percent of nitrogen that will give a return of the yield point in strained steel can be given by

$$x = \frac{100ND}{dAa} \quad \text{or} \quad x = \frac{200ND}{dAa}$$

where x is the weight percent of nitrogen,
N is the atomic weight of nitrogen (14),
D is the number of dislocation lines per sq. cm. of crystal,
d is the density of the steel (approx. 8),
A is Avogadro's number (6×10^{23})
and a is the lattice parameter of iron ($2{\cdot}86 \times 10^{-8}$)

For steel strained about 2–3%, the dislocation density is probably about 10^{10} lines per sq. cm., and if this value is put in the above expressions it is found that the weight percent of nitrogen to give a return of the yield point on ageing is only about 0·0001–0·0002%. If we now assume that 5 nitrogen atoms diffusing to each dislocation can give rise to a hardening precipitate, we find that the nitrogen content must be reduced below about 0·0005% to prevent any loss in ductility on ageing. This is in rough agreement with the critical figure found during the experiments on pure iron. This figure, however, is not generally obtained in regular steel works practice, except when a nitrogen stabiliser is added to the steel. The theory, however, does suggest that, up to a limiting value, the maximum loss in ductility due to strain ageing should increase with the amount of nitrogen present in the steel. It is significant, in this respect, that basic Bessemer steels, which have a high nitrogen content, are generally regarded as having most pronounced strain-age hardening characteristics. Unfortunately, there is very little quantitative data available in the literature to prove this point: one reason for this is that is is only comparatively recently that methods of analysis have been improved sufficiently to enable accurate nitrogen determinations to be made. The compilation of such data is also complicated by the fact that the results must be obtained on samples given approximately the same amount of plastic strain. Fig. 15 presents the only results of this sort that the author has been able to find. It shows the percentage reduction of ductility (total elongation on a 2 in. gauge length) due to ageing for 6 months samples temper-rolled 1·5%. The figures

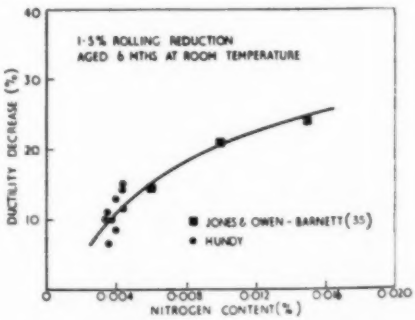

Fig. 15.—The effect of nitrogen content on the decrease in the total elongation (2 in. gauge length) due to ageing.

are taken from Jones and Owen-Barnett's paper,[35] and from the author's own work. As the nitrogen content increases, there is a marked increase in the loss of ductility due to strain ageing.

These results suggest that it is very desirable to adjust the steel making practice to keep the nitrogen content as low as possible, even though it could not be hoped to produce a non-ageing steel in this way. No normal method of steel making could be expected to produce a steel containing no nitrogen, but it might be possible to reduce the nitrogen content to 0·002% or so. This steel would still give pronounced strain ageing (the return of the yield point) but the strain-age hardening (loss of ductility) should not be so marked. Recent developments in the use of oxygen in converter steel making have lead to steels with low nitrogen contents (probably averaging about 0·004%[39, 40]) and it is possible that further advances may be made in this direction and that eventually a cheap steel with a very low nitrogen content may be produced commercially. It should also be borne in mind that if the nitrogen contents of mild steels could be reduced to as low as 0·002%, then complete stabilising with vanadium might become a very attractive proposition.

Conclusions

(1) The ageing of strained mild steel gives rise to a return of the yield point and to an increase in the tensile strength and a decrease in the ductility.

(2) The effect of ageing on the strength and ductility of rolled steel sheet becomes very much more marked as the rolling reduction is increased.

(3) These phenomena can be explained by postulating that ageing causes very small nitride precipitates to form at the dislocations in the steel, giving rise to a general hardening.

(4) The theory suggests, and experiment confirms, that it is advantageous to reduce the nitrogen content of deep drawing steels to as low a value as possible.

(5) Very low nitrogen contents are not yet within the reach of practical steel making, but it is possible that further advances in the use of oxygen in steel making may help in this respect.

Acknowledgments

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New Computing Service in London

THE ENGLISH ELECTRIC COMPANY has extended its comprehensive computing service by starting a new centre in its London Office, Marconi House, Strand, W.C.2. This centre is part of the Nelson Research Laboratories and operates in the closest collaboration with the organisation at Stafford. The service, which is available to organisations outside the English Electric Group, is provided by the D.E.U.C.E. (digital electronic universal calculating engine), the most powerful machine of its type in Europe. The machine is manned by a team of mathematicians specialising in the application of high speed digital computing to problems in all branches of mechanical and electrical engineering, and communications, aircraft, civil engineering and commerce. The computing service has behind it a unique and extensive library of programmes and sub-routines which have previously been prepared for the solution of many and varied problems. This library is compiled from all establishments who are using the D.E.U.C.E. extensively, and will be available to those using this new service.

Rolling Mill Drive Order

ELECTRICAL equipment worth over £250,000 has been ordered by Samuel Fox & Co., Ltd., from Metropolitan-Vickers Electrical Co., Ltd. It is for two hot reversing rolling mills, which are to be commissioned in 1957 at Stocksbridge Works, Sheffield; they will receive blooms of all types of alloy steel from a 36-in. blooming mill, one mill rolling billets down to 2 in. square, and the other producing rounds from 12 in. to 2½ in. diameter. The combined capacity will be 10,000 tons a week.

The new mills, the electrical equipment of which will be identical, will be driven by 4,000 h.p. (r.m.s.) 60/150-r.p.m. D.C. motors capable of taking peak loads up to 12,000 h.p. Each main motor is to be supplied from a motor generator set consisting of two 1,600 kW. generators driven by a 4,800 h.p. (r.m.s.) synchronous motor. The use of synchronous motors instead of the more usual slipring induction motors and flywheels will enable the mill drives to operate at a higher efficiency, as well as improving the power factor. The control system, incorporating amplidyne regulators, provides fast response and quick reversal with safe and reliable operation.

Low-Temperature Fatigue Testing of Copper

Improved Resistance to Failure

A RESEARCH project on the low-temperature fatigue testing of copper now being carried out at the Clarendon Laboratory by Dr. H. M. Rosenberg and Mr. R. D. McCammon is of considerable interest. Dr. Rosenberg is on the Staff of the Department of Physics of the University of Oxford, under the leadership of the Professor of Thermodynamics, Sir Francis Simon.

Many years ago, the use of piston-type expansion engines for the liquefaction of helium was thought to be rather unsatisfactory. Sir Francis suggested the use of expanding brass bellows instead of a piston and cylinder, but their reliability seemed at the time to be doubtful. After the recent war, however, a more efficient method of helium liquefaction became a matter of urgency, and a limited research programme was put in hand to establish if brass bellows could be safely employed for a liquid helium plant. The results of the tests came as a surprise. The resistance of the brass bellows to fatigue was found to mount extremely rapidly as the temperature fell.

After initial tests on brass rods at low temperatures, carried out to confirm the results obtained on brass bellows, further research was concentrated on copper, in order to avoid the complications introduced by the alloy structure of brass. Tests on pure copper rods showed an enhancement of fatigue life similar to that of brass. All further tests were therefore carried out on copper.

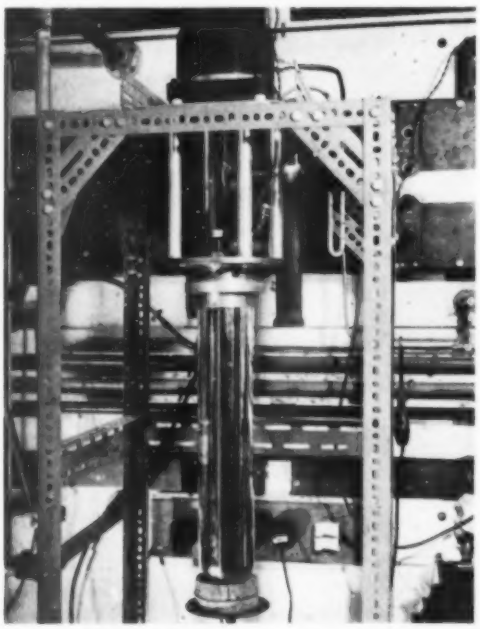


Fig. 1.—A connecting rod from the inverted Goodmans Vibration Generator at the top passes through a gland into the Dewar flask and applies an alternating load to the specimen.

Experimental Equipment

A special test rig had to be developed and is shown in Fig. 1. It comprises a framework of slotted angle, on top of which is mounted a Model 390A vibration generator.* The specimen is clamped in a fixed chuck mounted at the lower end of a tube, with cut-outs which enable the specimen to be viewed, as shown in Fig. 2. The upper end of the specimen is held in a moving chuck mounted at the lower end of a rod coupled to the armature of the vibration generator above it. The specimen tube, specimen and chucks are submersed in the cooling medium contained in a Dewar flask, which is silvered to prevent the transmission of heat, a narrow unsilvered strip being provided through which the specimen can be viewed during the test.

The definition " vibration generator " in this context may be misleading. The requirements for a motive unit for both fatigue and vibration testing are identical. Fatigue testing requires the application of a known force to the specimen at a constant frequency, and this is just what a vibration generator is designed to do. The armature of the unit, which contains the moving coil, is suspended in a pot-type magnet so that it is free to move axially. If a current is applied to the coil, it will tend to move in a direction determined by the polarity of the current. By supplying an alternating current, the armature can therefore be made to oscillate at the same frequency as the applied current.

A pure sinusoidal current is generated by a valve oscillator, amplified, and used to drive the vibration generator at the desired frequency. The model used in these experiments has a range up to 10,000 c./s. By incorporating a gain control on the amplifier, the current can be varied and, with it, the force applied to the component under test. The 390A model can apply an alternating force of up to 25 lb., but the largest model now available, the BG 109, can produce a force of up to 8,000 lb. These generators therefore provide ample scope for fatigue testing, especially since suitable stabilised driving equipment is also made, and the whole equipment is designed for continuous operation. The required working frequency of the oscillator is set by turning a control knob over a calibrated dial. In the present tests a constant frequency of 225 c./s. was used.

Fatigue and Tensile Tests

After the initial life tests, it was decided that, to enable the effects of work hardening during the fatigue experiments to be compared, all specimens should be tested at the same loading for the same time (6×10^4 cycles) at various temperatures.

Normally fatigue and tensile tests are carried out on different set-ups, and there is always the danger that removing the specimen from the one and clamping it in the other may damage it in some way. This applies

* Made by Goodman Industries, Ltd., Axion Works, Wembley, Middlesex.

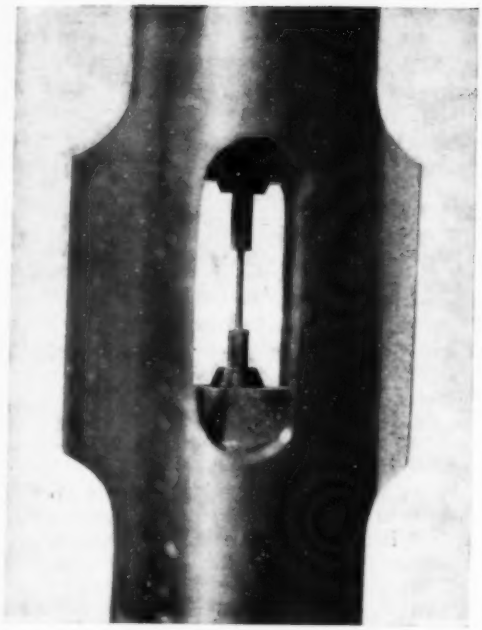


Fig. 2.—Close-up of specimen held in fixed chuck at bottom, the top chuck being fitted to the lower end of the connecting rod driven by the vibration generator. The entire assembly is immersed in the cooling medium.

especially to the delicate specimens used in these tests. The electrical equipment used provided a convenient solution, since it enables both tests to be carried out on the same set-up, without need to touch the specimen between tests. By simply feeding a known direct current instead of an alternating current to the moving coil, a known steady pull instead of a varying load can be applied to the specimen. By measuring the extension of the specimen with a travelling microscope, the stress-strain curve can readily be plotted.

This technique makes it possible to carry out tensile tests on specimens at very low temperatures, since the Dewar flask containing the cooling medium need not be removed. In practice, however, it has been found more valuable to test all fatigued specimens under identical conditions—at room temperature—to enable comparative results to be obtained. Since all specimens are tested for tensile strength under identical conditions, irrespective of the conditions applied in the previous fatigue test, it is possible to determine to what extent the effects of standard fatigue tests at different temperatures vary, or to what extent the fatigue tests must be modified with different temperatures to achieve the same effect.

Work Hardening Effect

Another interesting observation was that the first few tests indicated a fatigue resistance considerably smaller than that given by subsequent tests. After eliminating variable factors one by one, it was finally found that this apparent inconsistency was due to the different methods used in applying the load. If the test equipment was gradually run up to full load, fatigue resistance was always higher than when the full load was applied immediately. The extent of the effect of this factor on the results can be seen from Fig. 3. Results obtained on

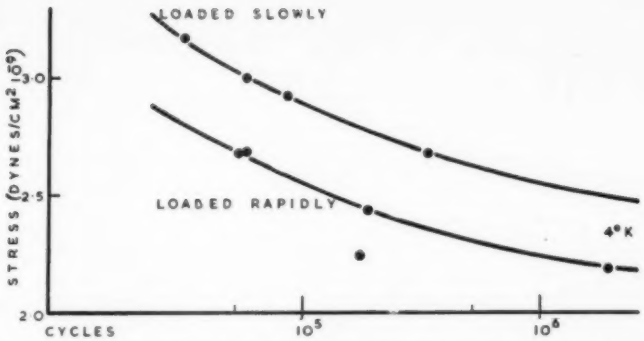


Fig. 3.—Difference in fatigue strength of specimens subjected to various stresses in liquid helium. Specimens loaded gradually (top curve) enable work hardening to take place before fatigue testing proper begins, resulting in greater ultimate strength.

mechanical test gear, which has to be run up to speed, might well be affected by this feature.

The reason appears to be that for copper, at least, work hardening is completed after about 30 seconds, most of it taking place during the first 10 to 15 seconds. If, during that period, the specimen is subjected to a safe load (a load which will not result in fatigue even if applied indefinitely), work hardening may be complete before fatigue testing has even begun. The subsequent fatigue test will therefore be carried out not on a standard soft specimen, but on a hardened specimen. Consequently, the test procedure was so modified that the vibration generator is preset and switched on only when the specimen is clamped and cooled.

Results

The tests were carried out at the following four temperatures: room temperature (approx. 293° K.), the boiling points of liquid oxygen (approx. 90° K.), liquid hydrogen (approx. 20° K.) and liquid helium (approx. 4° K.). The first fatigue tests indicated that copper, which had a life of n cycles at a given stress at 293° K., had a life of about $10n$ cycles at 90° K. at the same stress (an increase by a factor of 10), rising to about $100n$ cycles at 20° K. (a further factor of 10) and to $500n$ cycles at 4° K. (a further factor of 5).

There was also a considerable increase in ultimate tensile strength at low temperatures, although the relative increases were much smaller than those of the fatigue lifetimes. In an attempt to reconcile these different orders of magnitude, the next step was to determine the increase in stress which would be permitted in fatigue testing at various temperatures without reducing the life of the specimen, as compared with specimens tested at room temperature. A fixed cycle time was used, and the stress needed at the various temperatures to break the specimen in that time was found. The lower temperatures still gave the best results, as shown in Table I. The improvements were less dramatic, but still significant.

Continued on page 216.

TABLE I.

Approximate Temperature (° K.)	Life of Similar Specimens at Fixed Stress (cycles)	Stress to Give Fixed Life with Similar Specimens (dynes/sq. cm.)	Ultimate Tensile Stress of Similar Specimens (dynes/sq. cm.)
293	n	s	s'
90	$10n$	$1{\cdot}5s$	$1{\cdot}5s'$
20	$100n$	$2s$	$2s'$
4	$500n$	$2{\cdot}2s$	$2{\cdot}2s'$

New Indian Iron and Steel Works

Entire Project to be Handled by British Group

ANNOUNCEMENT of the signature of an agreement setting out the terms under which a British consortium—the Indian Steelworks Construction Co., Ltd., known as ISCON—will construct an iron and steel works for the Government of India, reflects the ability of British firms in the steel plant industry to undertake a project of this magnitude at competitive prices, and to make a major contribution to the industrialisation of a leading Asian country. Costing about £80 million, the works will have an initial capacity in excess of one million tons of ingots a year. The announcement indicated that the plant would produce 300,000 tons of foundry grade pig iron and 790,000 tons of medium structurals; blooms and billets for forging and re-rolling; and railway wheels, tyres, axles and sleepers. Expansion of steel production in India is regarded by the Government as an urgent priority, and the British plant to be built at Durgapur in West Bengal is one of the three, each rated at about one million ingot tons a year, which will be under Government ownership, and which are to be completed during the period of the second five year plan.

Wide publicity has already been given to agreements which the Government of India has concluded with the Krupp-Demag group of Germany and with the U.S.S.R. in connection with the other plants. In 1953, the Krupp-Demag group undertook to act as consultants to the Government for a flat products plant which is to be sited at Rourkela. For the work of placing orders for the plant, site development, and construction and commissioning of the works, the Government has created the Hindusthan Steel Co., Ltd. The agreement with the U.S.S.R. relates to a structural steel plant to be built at Bilhai. It is understood that the equipment will be supplied by the Soviet Union, and the construction of the plant will be undertaken by the Government of India with the assistance of Soviet specialists.

It is a matter of interest that, whereas the Government of India is to undertake the tasks of site development and construction of the works for the Bilhai and Rourkela projects, it will be relieved of these major responsibilities at Durgapur, as the British consortium has undertaken to build and hand over the works ready for operation.

To achieve its target of six million tons of ingots a year by 1961, the Government of India is also carrying out major development and expansion schemes in the fields of transport, hydro-electric and thermal power generation, and mining. The three million tons of ingots from the Government-owned plants will be supplemented by an equal amount to be produced by the Tata Iron and Steel Co., Ltd., and the Indian Iron and Steel Co., Ltd. The former company has commenced work on a scheme for adding some 750,000 tons of ingots to its present capacity and will, by 1959, be producing two million tons of ingots per year. While the six million ton target represents an enormous increase over present production, it is now considered in India that even further expansion will be required to meet the demands of the country.

Early Negotiations

When, in 1954, the Government of India announced its intention to raise steel production capacity in the country, the British consortium, the Metallurgical Equipment Export Co., Ltd. (MEECO)—comprising Davy and United Engineering Co., Ltd.; Electric Furnace Co., Ltd.; Head, Wrightson & Co., Ltd.; Joseph Parks & Son, Ltd.; Simon-Carves, Ltd.; and The Wellman Smith Owen Engineering Corporation, Ltd.—offered its services for the complete engineering, supply of plant and construction of steelworks in India. At the request of the Government, it also provided, early in 1955, an indication of the costs of building a works with a capacity of some 700,000 tons of structural steel a year, and suggested a means of financing the purchase of plant and equipment from the U.K.

Almost simultaneously, Her Majesty's Government offered, under the terms of the Colombo plan, a British technical mission to advise on the development of the industry in India. Such a mission, under the leadership of Sir Eric Coates, visited India in April, 1955, and its report, presented early in August, won praise for its thoroughness and the soundness of its recommendations.

Covering, as it did, advice on the selection of a site, the products to be manufactured, the use of raw materials, and recommendations for the plant and processes to be employed, with estimates of the costs of development, the report provided a sound basis for discussion in the negotiations which the Government of India commenced with the Indian Steelworks Construction Co., Ltd., in October, 1955.

Credit for the conception of this consortium lies with the Board of MEECO, who laid the foundations of ISCON early in 1955. This company, which was formed for the express purpose of undertaking steelworks construction in India, includes the following British firms: Davy and United Engineering Co., Ltd., Head, Wrightson & Co., Ltd., Simon-Carves, Ltd., and The Wellman Smith Owen Engineering Corporation, Ltd. (for the engineering and supply of mechanical plant and equipment for the principal sections); The British Thomson Houston Co., Ltd., The English Electric Co., Ltd., The General Electric Co., Ltd., and Metropolitan-Vickers Electrical Export Co., Ltd. (for all electrical machines, plant and equipment); Joseph Parks & Son, Ltd., Sir William Arrol & Co., Ltd., Dorman Long (Bridge & Engineering), Ltd., and Cleveland Bridge & Engineering Co., Ltd. (for the fabrication of structural steel for buildings, etc.); and The Cementation Co., Ltd. (for all civil engineering work at site).

The potential of the ISCON consortium and its ability to undertake the construction of a complete steelworks on a green-field site will not be doubted. Although this is probably the first occasion on which a consortium of this type has been formed, what is important is that

these manufacturers of heavy electrical and mechanical plant and civil engineers have come together so willingly to ensure that this substantial oversea contract should not be lost to this country. The magnitude of scope of the project will certainly benefit not only the companies of the consortium, as a large number of sub-contracts will be placed with manufacturers of ancillary equipment not produced by the companies themselves.

Financial Aspects

Soon after the report of the U.K. Steel Mission had been delivered to the Government of India, ISCON offered its services for the construction of a large steelworks in India and, by arrangement, Sir Cyril Jones, chairman of the company, led the first ISCON mission to India in October, 1955, for discussions with representatives of the Government and their consultants, International Construction Co., Ltd. General agreement was quickly reached on the capacity and products of the projected plant, the raw materials to be used, the processes to be employed, and the main plant units to be installed.

As called for by that agreement, ISCON submitted its proposals and preliminary prices to the Government of India on January 15th, 1956. The second ISCON mission, which included both technical and financial representatives of the company, visited India in February, and in March the recently announced agreement was signed. Final prices and proposals will be submitted by ISCON in May, and it is expected that the contract will be negotiated in June, in which case manufacture and site work will commence in July, 1956.

Of the total estimated cost of about £80 million, the sterling contract value covering supplies and services will be in the region of £52 million, and the balance will relate, amongst other things, to the fabrication of some 30,000 tons of steel in India, and the provision of Indian materials and labour, and will represent the rupee expenditure.

The financial arrangements for a project of this magnitude normally present a major problem, but in this instance the prompt decision of the Government of India to utilise approximately £25 million from its sterling balances contributed materially to a solution of the problem. Towards the balance of the sterling contract, Her Majesty's Government have made a loan to the Government of India of £15 million, and a credit facility to the value of £11·5 million has been arranged by Lazard Brothers & Co., Ltd., with Lloyds Bank, Ltd., Barclays Bank, Ltd., Martins Bank, Ltd., Glyn Mills and Co., and the District Bank, Ltd.

Active consideration is being given to the training of personnel for management and operation of the plant, and arrangements are being made in Britain to give every assistance in the training of key Indian technicians and operatives.

The speed with which agreement between the Government of India and the Indian Steelworks Construction Co., Ltd., has been reached, is evidence of the mutual goodwill which characterised the negotiations. Members of the U.K. Steel Mission and representatives of ISCON who have been engaged in the negotiations, have been impressed by the impartial and efficient way in which the many proposals and problems, inevitable in a project of this magnitude, have been dealt with by the representatives of the Indian Government and their consultants.

That the prestige of British manufacturers and banking houses would be enhanced abroad by a contract of this order has been fully recognised in this country, and both the Metallurgical Equipment Export Co., Ltd., and Indian Steelworks Construction Co., Ltd., appreciate and gratefully acknowledge the encouragement and assistance they have received throughout from all departments of Her Majesty's Government and their oversea representatives.

The New Plant

The British plant is to be constructed at Durgapur, about 110 miles north-west of Calcutta, and on the River Damodar and the railroad from Calcutta to Delhi. Coal and iron ore hauls will be some 50 to 70 miles for normal supplies. Production of pig iron is to commence in June, 1959, when the first coke oven battery and blast furnace will be in operation, and the entire works will be completed in March, 1961.

The plant has been planned and designed to ensure an annual output of a million tons of ingots and up to 350,000 tons of foundry pig for sale. However, the capacities of the coke ovens, blast furnaces, steel plant and primary rolling mills are adequate for 1¼ million tons of ingots. The general layout and plant units have been planned to allow for convenient doubling of the production.

The works may be considered as made up of the four principal sections referred to above, and ancillary service departments, which include the power house, maintenance shops and foundries. The work undertaken by the member companies is outlined below, and it is stressed that their responsibilities are not limited to the supply of plant: the manufacturing companies have also been responsible for the engineering of those sections for which they will provide the plant.

The technical co-ordination of the principal sections and ancillary departments, the engineering of the services for gas, water, steam and air supplies, and the planning of road and rail facilities have been carried out by the engineering department of MEECO. For all electrical work, MEECO and ISCON have as their consultants Messrs. McLellan and Partners.

Coke Ovens

Simon-Carves, Ltd., will be responsible for the complete coal preparation plant, including a feldspar jig washing and a coal stocking, blending and reclaiming plant on the Robins-Messiter system; three coke oven batteries (each of 78 ovens) to carbonise a total of 5,200 tons/day of dry coal, which will be a blend of Barakar and washed Jharia coal; and a coke screening and handling plant up to the blast furnaces capable of dealing with 3,900 tons/day of run-of-oven coke. The Simon-Carves by-product plant will cater for the recovery of crude tar, benzol, and sulphate of ammonia: a contact sulphuric acid plant is also included.

Blast Furnaces

Head Wrightson & Co., Ltd., have been entrusted with the construction of three 27-ft. hearth diameter blast furnaces, each capable of producing over 1,000 tons/day of pig iron, and equipped with twin skip hoists. The hot blast to each furnace will be supplied by three stoves of the two pass design with side combustion chamber. The handling equipment will supply ore to a Robins-Messiter blending plant having four storage piles and two reclaiming machines. The whole plant will be capable of handling 45,000 tons/week of ore, the average

iron content of which, as fed to the furnaces, will be in the region of 55%. Provision for the installation of a sinter plant at a later date has been made.

Hot metal from the furnaces (one of which will normally produce foundry pig iron for sale) will be handled by 75-ton hot metal ladles and two double-strand pig casting machines having a total capacity of 240 tons/hr. Slag will be removed in Head Wrightson-Treadwell slag ladles and carriages. Gas cleaning equipment will include primary and secondary dust catchers, Head Wrightson-McKee washers, and Head Wrightson Research-Cottrell electrostatic precipitators.

Steel Plant

Construction of the entire steel-making plant and ancillary equipment will be undertaken by The Wellman Smith Owen Engineering Corporation, Ltd. It will include two 800 ton inactive mixers, and eight fixed 200 ton and one fixed 80 ton basic open hearth furnaces. Oxygen from two 50 ton/day units will be provided for de-siliconising hot metal in transfer ladles after leaving the mixers, and for lancing in the open hearth furnaces. The furnace charging system for cold charges will be by ground charging machines, with a high-stage charge holding bay and a yard-level scrap loading gantry.

Two vertical shaft lime kilns and one horizontal rotary dolomite kiln are to be conveniently located, and their products will be delivered by conveyor belt to bunkers in the charge holding bay. Mould preparation and stripping will be carried out in separate buildings, and provision is also being made in a separate shop for up-casting of ingots for the wheel, tyre and axle plant.

Rolling Mills

Davy and United Engineering Co., Ltd., will build the rolling mills and wheel, tyre and axle plant: the provisional production programme is as follows:—

Forging Blooms (Medium and Heavy) ..	40,000 tons
Forging Billets	60,000 tons
Billets for Re-rolling	150,000 tons
Merchant Bar Sections	240,000 tons
Light and Medium Sections	200,000 tons
Sleepers	60,000 tons
Axles	12,000 tons
Wheels and Tyres	28,000 tons
Total	790,000 tons

The primary rolling mill plant will comprise ten bottom-fired recuperative soaking pits, each capable of holding twelve standard 7 ton ingots, a 42 in. blooming mill and a 32 in. intermediate mill. The finishing mills include a 24 in. medium section mill, a Morgan continuous billet and sleeper bar mill and a Morgan merchant mill. Equipment in the wheel, tyre and axle plant will include a 6,000 ton wheel forging press and 2,000 ton dishing press, wheel and tyre roughing and finishing mills, and a machine shop.

The 32 in. intermediate mill will be manufactured by Brightside Foundry and Engineering Co., Ltd., whose collaboration in this project has been sought by Davy and United Engineering Co., Ltd., in order to spread the work and thereby assist delivery.

Ancillary Plant and Equipment

The central power station, which will be engineered and built by Simon-Carves, Ltd., and the four electrical companies, will include four gas-fired boilers, each rated at 150,000 lb./hr., of which two will be equipped for alternative solid fuel firing, and three 5,000 kW. turbo-alternators and four large turbo-blowers.

The engineering workshops will provide for all normal maintenance of plant and works rolling stock. A foundry for ingot moulds and a general foundry for ferrous and non-ferrous work are included in the layout. Responsibility for the engineering of these departments has been undertaken by Davy and United Engineering Co., Ltd.

The electrical plant and equipment will be provided by the British Thomson-Houston Co., Ltd., the English Electric Co., Ltd., the General Electric Co., Ltd., and Metropolitan-Vickers Electrical Export Co., Ltd., and will include about 2,500 motors of sizes up to 7,000 h.p., for the rolling mill drives. In addition, they will be responsible for the general distribution system, comprising nearly 100 transformers and rectifiers and 700 switches and circuit breakers of voltages up to 30,000, as well as for the lighting and telecommunication systems and a vast quantity of cable.

Structural Work

For the supply of all structural steel buildings, responsibility will rest with Joseph Parks & Son, Ltd., Dorman Long (Bridge & Engineering), Ltd., Cleveland Bridge & Engineering Co., Ltd., and Sir William Arrol & Co., Ltd. Some 60,000 tons of steel buildings will be fabricated.

The Cementation Co., Ltd., will undertake in India, with the Patel Engineering Co., Ltd., of Bombay, all civil engineering work. The cost of the civil engineering work will be in the region of £15 million, and will include all concrete work, the laying of railway tracks, roads, water service mains, drainage systems, etc., and construction of the buildings for offices, laboratories, canteen and other amenities.

Construction Programme

According to the tentative construction programme major plant units will be installed as follows:

Stage I—The first coke battery, first blast furnace and pig casting machines, with services and transport to suit, and part of the work-shops, in June, 1959.

Stage II—The second coke battery, second blast furnace, part of the steel plant, and the rolling mill up to the billet mill stage, in December, 1959.

Stage III—The third coke battery, the third blast furnace, and the remainder of the workshops, steel plant and rolling mills, in December, 1960, and the wheel, tyre and axle plant, in March, 1961.

Low-Temperature Fatigue Testing of Copper

Continued from page 213.

The broad similarity between the relative improvements in both ultimate tensile strength and fatigue resistance is too marked and regular to be a mere coincidence, and suggests that the same mechanism is responsible.

The method developed at Oxford seems to offer opportunities for a fresh approach to the whole problem of fatigue. Variation of temperature has been proved to be an effective means of changing the properties of copper without altering the composition or mechanical structure of the specimen in any way. The change in temperature can thus be considered as the single external variable. It now remains to determine what internal effects are caused by temperature variation to give rise to the observed changes in fatigue resistance and ultimate tensile strength.

Science, Commonsense, and Good Management in Industry

A Consideration of their Relative Importance

As the last of a series of weekly lectures comprising the largest engineering refresher course ever to be held in this country, organised by Incorporated Plant Engineers, The Earl of Halsbury, F.R.I.C., F.Inst.P., Managing Director of the National Research Development Corporation, discussed the directions in which our industries require more intensive application of science, and those in which they require the application, not of science, but of commonsense and good management. A condensed version of Lord Halsbury's address is presented here.

THE world is not run by exceptional people. This is a lesson that exceptional people very often have to learn the hard way. The world in fact is run by ordinary people, which is a very good thing ; for ordinary people are those who constitute the great majority of the world's population, and it is right that they should run their own affairs.

All professional people—lawyers, doctors, engineers, scientists and so on—are to some extent exceptional, in that they confine their activities to a narrow slice of the world in which they live, and within that narrow slice they operate in terms of adequate information, rationality, intellectual good order and discipline. Of course their professional slice has a boundary where it meets the partial chaos and turbulence of the ordinary man's world, and towards that boundary the professional man becomes less sure of himself, less rational, less dominating. But there is always a heartland, a fortress remote from the boundaries, where he dwells secure for the greater part of his time : the doctor with his anatomy, the lawyer with his statutes, and the scientist with his conservation laws.

If the world could be compartmentalised into slices, each dominated by such exceptional persons, the whole conduct of human affairs could be entrusted to the professional integrity of experts. In the words of the Communist philosopher, Friedrich Engels, the government of men would give way to the administration of things. Fortunately or unfortunately, depending on how you regard it, the world cannot be completely compartmentalised in this way. The range over which intellectual good order can be maintained is small compared with the whole turbulent range of human affairs. Experts are sometimes unaware of this. Their mind's eye being focused on the intellectual discipline of their own subject, they tend to assume that their neighbour's house is at least as orderly as their own. Further, they tend to overestimate the number of professional neighbours they possess, taking at its face value the brass plate engraved 'Expert' so clearly resembling their own and affixed to the porch of the house next door. There are, in fact, very few genuine fields of expertise.

Real expertise only begins where general principles emerge. The fields where this has happened are few and far between. One such field is occupied by the mathematical, physical and chemical sciences, now so completely merged into a single intellectual discipline that we commonly, but incorrectly, refer to it as " Science." A second field is occupied by the biological and medical sciences which, inspired by the same ideals as inspire the physical sciences, have brought order and discipline into the study of living systems.

A third field is that occupied by the social and psychological sciences, of which critics have complained that either they do not exist, or cannot exist or ought not to exist, I am never quite sure which. They are certainly immature as compared with their elder brethren, but their practitioners are inspired by the proper ideals. To that extent at least they are sciences, even if young ones.

Application of Science in Industry

The results of scientific research are commonly applied in industry. If we regard this application as having begun about two hundred years ago, and classify all industries prior to that date as traditional, then it is true to say of a modern industrial state that its traditional industries have been transformed out of recognition, the main sources of its wealth displaced to non-traditional industries, and its standard of living elevated beyond the dreams of its forbears by the application of science. Since the difference between the total wealth of the world in 1756 and 1956 is a consequence of the world's total expenditure on research in that period, it would appear that, regarded globally, research is the highest yielding form of investment so far discovered, with this peculiarity, however, that there is no property in the knowledge thus characteristically applied. Research pours knowledge into a world pool, a pool *to* which all contribute, and *from* which all draw. There is no property in the pool, and it needs a high degree of inspiration to prophesy which of its many fish will next be the one to spawn wealth in incalculable millions.

One consequence of this is that we are advised on all sides to apply science ever more intensively to our industries, and the object of my paper tonight is to enquire in what directions our industries require more intensive application of science, and in what direction they require, not the application of science, but of commonsense and good management. For it is my belief that we scientists are sometimes in danger of defining industry as " whatever we can apply science to " and ignoring whatever doesn't fit in with our definition.

Only about a quarter of all those gainfully employed are directly concerned with manufacturing industry. If

we could do with 10% fewer people on administration, services, and indirect operations, we could have 30% more people employed in direct production, and we should have 30% more goods. Assuming that we can earmark a certain effort for the overall advance of our industries, where ought we to expend it? On training more scientists to transform our direct production, or on reorganising the majority whose connection with production is indirect? These are fair alternatives, and even if you decide for " a little of each " you have still to decide on the proportionate allocation of effort between them.

Industry trades not only with suppliers of raw materials on the one hand and consumers of finished products on the other, but extensively with itself. Inter-industry transactions represent a large proportion of industry's output. Textile factories, for instance, do not as a rule design their own machinery. They buy their machinery—cards, combs, ring spinners, looms and so on—from other factories. Automobile factories do not as a rule make their own machine tools: they buy them from machine tool manufacturers.

Research May not be the Answer

It is important not to be hypnotised by spectacular applications of science in one field, nuclear energy say, into supposing that the performance can be repeated in arbitrary fields, merely by virtue of the wish to do so. We can only apply science to what is under our own control. Commonsense suggests that before becoming oversold on the application of science to industry one should be clear as to which of its applications lies under one's own control and which under the control of other people. We ourselves control what we shall buy, how we shall use it, and the rate at which we will replace it. We do not of course, control these things absolutely, since economic factors set limits upon our freedom of choice, but within these limits there is scope for policy making. When we have made up our mind on all these issues, what is there left over for science to do, and how important is it? If we decide that there isn't much left over, and that what remains is of no great importance to the business, let us have the courage to say: " We don't need a research laboratory." We will probably be quite right. Don't misunderstand my advice on this point however. Change the emphasis in the above sentence, placing it upon each word in turn.

" *We* don't need a research laboratory." True, but others may, particularly our suppliers. If our welfare depends upon research in another industry, let us be sure that other industry is doing the research necessary, and embodying it in the products we are going to buy. Failing this, let us change our suppliers to new ones who will do their job.

" We don't need a *research* laboratory." True, but we may need a laboratory for trouble shooting on the works and customer sides, and for control purposes. Let us make sure the cost of it is allocated to the works and sales departments in fair proportions. The works and sales managers will then get the service they are prepared to pay for. They will usually accept the allocation cheerfully. If we call it research, they will grumble and cut down on the cost when times are hard, complaining that it never gets any results (naturally enough!).

" We don't need a research *laboratory*." True, we may not need a laboratory under our own control, but we will certainly need to be kept in touch with reports of advances in our field. We will need consultants, and we will get better value by joining the appropriate industrial research association, and using its services enthusiastically, than by setting up inefficient laboratories to do small-scale research on our own. What to buy, how to use it, and how soon to replace it are, as I have said before, within limits, our free choices. But we will choose much better in respect of the first two factors if we have ready access to third party opinions from studious and friendly critics of our equipment. On the issue of how to use equipment, you can get much good advice from your suppliers, and still more from your industrial research association.

The best way to get good value from your equipment is to employ well trained personnel to run it. The cheapest way to train personnel is to pay someone else to do it for you. On the whole, I think the Government does this more cheaply than almost anyone. I don't believe in parents trying to educate their children; they lack time, patience and didactic skill. For the same reason, I don't believe in industries training their own personnel, unless they do it in properly organized apprentice schools. You need a steady intake of the products of our national system of education, the output of our technical and technological colleges and universities, and you must pay them wages and salaries which will enable you not only to hire them but to keep them.

Research is no panacea for archaic equipment, a low rate of replacement, inefficient use of machinery, poor labour relations and poor quality technical staff. If you suffer from any of these things, do not let anyone blind you with the need to rescue the factory from the consequences of old mistakes by means of research. May I tell you the story of a group of industrialists who asked my advice on how to spend £50,000 a year on research designed to increase productivity in their industry? The conversation went as follows:—

" What on earth do you want to spend £50,000 on research for? "

" To raise productivity in our industry."

" What's wrong with productivity in your industry? "

" American output per machine hour is twice ours."

" It sounds as if what you want is not £50,000 a year for Research but £50,000 a-piece for some American machines."

" Oh, we've got American machines."

" Then why don't you get the productivity? "

" It's the speed. They run their machines twice as fast as we do."

" Then it sounds as if you want about £5,000 a-piece for some new electric motors."

" Oh, there's nothing wrong with the motors; it's just that the Americans know how to run the machinery faster."

" Then it sounds as if you need about £500 a-piece for sending your staff across the Atlantic to take some lessons in how to run the machines. Would your American friends co-operate? "

" Oh, they've shown us all they know; the trouble is we can't apply it."

" I am sorry, but this is ceasing to make sense. Are you asking me to believe that our national intelligence is so far below the American level that we cannot copy their performance when shown how."

" No! It's the quality of the labour they use..."

" Ah! "

"They employ graduate engineers and chemists to run the plant. We employ general labourers."

"Well it seems you know the answer: 'Go thou and do likewise.' What we finally establish is the need for some staff recruitment based on advertisements at £50 a-piece. I'm glad the cost is coming down!"

"But you can't *do* that in England!"

"Why not?"

"The unions wouldn't stand for it?"

"Have you ever asked them?"

"No. But this is *England*; you can't expect British graduates to work continuous shifts operating a plant!"

"How much do you pay your graduate staff on engagement?"

"Fresh from the university—from £600 to £800 a year."

"Have you ever tried offering £1,500—to get their hands dirty and work shifts?"

"No."

At this point the conversation passed from the control of the technical director and director of research of the concern which was consulting me to their managing director, who had hitherto been listening. He commented "This is the point at which all our discussions invariably bog down. I can see the sense of what you're driving at, and I would like to do what you recommend; but until I can get my technical advisers to endorse what I want, I do not feel justified in overruling them."

Now I find this situation extremely interesting. The managing director was by profession a chartered accountant, the technical director an engineer, the director of research a chemist. None of them was a fool; they were in fact all highly intelligent men; yet they were all in a muddle. There is a school of thought which regards the promoted accountant as a uniformly baneful influence in industry. I do not accept this view, though it may be true in one or two cases. Professional people, be they accountants or technical men, are generally promoted to board levels for their personal rather than their professional qualities. Exponents of the school of thought which condemns the promoted accountant and seeks to replace boards of directors with committees of engineers would, I am sure, jump gleefully at the above anecdote. "A low productivity, an accountant at the helm—isn't it only too obvious what the connection is?"

Well, it isn't obvious to me. Of the three men concerned, the accountant was, in fact, the most open-minded of them all. *He* knew the answer and was prepared to face its implications, if only he could carry his technical colleagues with him. And yet he too was, in one particular, muddled. Determined to mind his own professional business and not to interfere with the responsibilities associated with the professional skill of others, to act by persuasion rather than by fiat, he failed to notice that his colleagues were not abiding by his own standard of professional conduct, and were, in fact, exceeding the bounds of those subjects on which they were qualified to pronounce. One was an engineer; the other a chemist. Each was making pronouncements in a voice of pretended authority on a subject which concerned neither engineering nor chemistry—the subject of human relations in industry. Neither seemed aware that he could get good expert advice from consultants in this field. Each approached it with an amateurishness he would have condemned in his own professional field. Finally, all three fled to a sanctuary labelled "Research" as the only escape from the impasse.

I feel that I should add a sequel to this story. I followed it by going to an institute which specialises in industrial relations, and recounted it there. The director of the institute smiled and referred my friends to another firm, in a different field, which had successfully tackled and solved the problem currently worrying them. The unions *had* agreed; graduates *would* work shifts; in at least one case American machinery was being run at American speeds by British graduates working shifts in England with the blessing of the unions.

In critical moments each of us with industrial responsibility must ask himself "What is wrong with my industry?"... "What can I do about it?" It is important not to indulge in some form of escape mechanism at this point. Many industries could say in reply to this rhetorical question: "The price of raw materials." The price of raw materials, however, is the same for everybody. If it makes business more difficult to finance, one might just as well blame the bank rate. One commonly encounters a situation in which an industry is not purchasing the most modern equipment in significant quantities, and sometimes defends itself on the grounds that the most modern equipment is only economic on the basis of double shift working, and that foreign industries are able to do this, but that our own industries are not, due to the attitude of the unions.

The Social Sciences

If you believe this in any particular case, then you must also believe that it us useless to run to the chemist, the physicist or the engineer to get you out of the difficulty with which you are faced. What you need, as the logical consequence of what you believe, is better labour relations. The sciences you must turn to are not the mathematical, physical or chemical sciences, but the social sciences. There *are* such sciences. Do not despise them because they are young, and their practitioners operate in a difficult field. They are young *because* they are difficult. The easy fields are always the first to be opened up. Mathematics is child's play compared to sociology, I can assure you.

I have in mind that I am addressing technologists. I do not expect you to be industrial psychologists as well. Above all I do not seek to persuade you to become amateur psychologists—a fearful menace. You ought, however, to know that these sciences exist. You ought to know that up-to-date firms employ professionally trained personnel managers, and that consultants *can* be engaged to help them. You ought to insist on your firm employing the one and engaging the other when the need arises. You ought to insist that, when you have a labour-relations problem on your hands, it is tackled on a professional and not an amateur basis. For, if you do not shoulder this responsibility, be assured that no one else will. You ought to be the link between your employers and *all* the sciences. It is your business to know what sciences there *are*, and to bring them to your employers' notice.

I would not like you to think that any one industry alone provides examples to illustrate my theme. Let me draw on several.

A large and very up-to-date engineering firm recently analysed the activities of its planning staff. Out of every 100 men, 44 engaged on direct production had every detail of their work planned for them, so that not a minute of their day or a foot-pound of their energy was wasted. Forty-eight men were required to support the

productive 44 with auxiliary services of one kind or another. Their activities were totally unplanned: they were simply taken for granted. Eight men were required to do the planning for the 44. The total make-up was therefore as follows:—

Planned for	44
Unplanned-for	48
Planning	8
	100

"How silly it looks, when you get around to looking at it that way!" one of their directors remarked to me, and added "I wonder how many other crazy things we're doing that we haven't yet spotted?" Here again, you see, is an example where some managerial stream-lining is likely to produce just as big a dividend as laboratory research.

Particular Industries

Let me consider a few specimen industries from one standpoint only, namely the factors that mainly control their commercial success. The result exhibits the very wide variation in these factors and shows how elastic must be the approach to a strategic consideration of research problems.

Soft Drinks, e.g., Bottled Soda Water.—The product is substantially water and carbon dioxide. It cannot differ materially from competitive soda water, though a drop of this or a pinch of that per ton may contribute something intangible to the flavour. Bottles, labels, washing, bottling and labelling machinery can probably all be bought out without materially affecting the economics of the business. Its success must depend on management, distribution, sales promotion and advertising techniques. From time to time some new drink, such as Coca Cola, engages the public taste, but no one would describe the cookery book procedure leading up to enterprises of this kind as "Research" for any purpose other than sales promotion. Customarily one tins peas and bottles beer; there is no reason to suppose one could not invert this procedure, bottling peas and tinning beer. In fact, canning beer has taken on in the U.S.A., and has some economic advantages over bottling. Any such modification no doubt entails problems whose solution requires that combination of detective work and honest enquiry, methodically undertaken, which is known as trouble shooting to scientists and as research to salesmen. It seems unlikely that what one might call "deep" research has much field for application in this industry.

Automobile Manufacture.—Success depends upon an extremely delicate gauging of how many automobiles of a particular style and performance the public will buy, at a given price over a given period, before their interest begins to fall off in favour of an advanced model of competitive design, calling for a restyling and redesigning for selling reasons. If this guess is made correctly, then success will follow under the guidance of experienced engineers and production managers who can calculate costs very closely. Recovery of tooling costs over the run is essential, as the factory must tool up in a major sense for several, say five, years ahead. But the industry does not *make* its machine tools, or cutting or grinding materials. It buys them out, together with a high proportion of the components which it assembles into the finished product. Many of these auxiliaries, e.g., tungsten carbide cutting tools, may embody the results of deep and prolonged research, but the automobile industry does not originate them, it exploits them. Organisation, production engineering and designing seem to dominate the factory. I try to think of a development in automobile engineering where the scientist rather than the engineer took the initiative and one comes readily to mind: a Ford backaxle of pre-war days made from a precipitation-hardening, copper-containing steel. No doubt there have been others, but they do not press urgently on the memory. In the automobile manufacture and assembly industry, the physicists and chemists in fact appear to be the servants of the engineer; they do not take the initiative, in contrast to chemical or nuclear engineering, where their rôles are reversed, the engineer being the servant and the physicist or chemist the master.

Decorative Textiles.—Here, as in automobile engineering, style and design will determine the sale of a product in a competitive market, but the finely balanced recovery of tooling costs characteristic of the automobile industry is not a feature, since a new fabric design does not within wide limits imply the need for a new loom or printing machine to weave or colour it with. Deep research, as opposed to trouble shooting, would not appear to be a very profitable field for investment.

Steel Production.—This represents yet another contrast in terms of an enormous capital investment in integrated equipment: coke ovens, sintering plant, blast furnaces, steel furnaces, soaking pits, and rolling mills. A plant so conceived will be designed to last at least a quarter and perhaps half a century. As built, it will represent the most advanced engineering of its period; but it will be quite rigid and unadaptable to modification or experiment, for it must be kept working 24 hours a day, 7 days a week. Doomed to progressive obsolescence over many decades, such plants are admirable fields for operational research—enquiries designed to ascertain the optimum way of employing a fixed facility.

Chemotherapeutic Agents.—Here the whole picture changes. The chemical, biological and psychological branches of science have united in a pyrotechnic display of achievements that seem to flow on in a never-ending stream. Without deep research, none of this would be possible, and it is difficult to assign the current genesis of this stream of results unambiguously to industry or to the universities. Each is heavily engaged in producing the results. A pharmaceutical house without a research laboratory amply financed would be a contradiction in terms. The engineer accordingly becomes the overtaxed servant of the biochemist almost vainly endeavouring to obtain production of results before they become obsolescent.

Aeronautical Industry.—Here we find another pattern. As in the automobile industry, the designer and the production engineer dominate the industry but the designer is here engaged not in evolving a style to please a customer, but in a battle of wits against nature to achieve the barely possible with the barely constructible. Here the words "trouble-shooting" lose their meaning, since virtually every problem is a deep problem, and all research is deep research. Here the physicist studying turbulence, the aerodynamicist exploiting the physicist's knowledge in the design of a wing, and the aeronautical engineer seeking to fabricate it are all one team, none of

them dominating the others, since each may be the one to make the next advance.

The foregoing examples are not intended to review our industries, but to illustrate their diversity. It is this diversity of industry which should occupy our thoughts whenever we consider how science should be applied to it.

There is no answer to the enquiring industrialist who asks "How much should I spend on research?" Who is the speaker supposed to be? A wine merchant in the Port trade? A building contractor? A pharmaceutical house?

Generally he must answer his question for himself, after thinking about it with some understanding and insight. What is his business? On what factors does its prosperity chiefly depend? On buying, equipping, employing processing, distributing, advertising or sales promotion? When he has made up his mind that his success and prosperity depend on factors to which science rather than competent management can make a contribution, he can start collecting estimates from advisers in relation to the cost of solving his problems with a reasonable chance of success within, say, ten years. When he has his estimates, he should ask himself whether he can afford the indicated rate of expenditure through three adverse trading years. If not, he should prune his list to what he can afford under these conditions, and then see if what remains is a viable programme. If the result of these reflections is all favourable, he should go ahead courageously. If it is not, he should recognise the logic of events and of his position in industry. Pseudo-research is no substitute for competent management and up-to-date equipment, a professionally skilled team of employees, and a determination to compete and expand.

The course which you have all attended here in London is the kind of activity which I heartily endorse. It is not sufficient for industry to have well designed plant. It must have well designed and up-to-date plant. By the same token it is not sufficient for industry to employ well trained professional staff to operate and maintain the plant. The training of their professional staff must be kept up-to-date. Refresher courses of the type which you have attended are a typical means for effecting this purpose. Your own and your employer's willingness to support them by your attendance should be a matter for congratulations to all concerned.

Furnace Rebuilding Programme Increases Output

BY the beginning of February, 1956, the fourteenth and final open hearth furnace in the Templeborough melting shop of Steel, Peech and Tozer, a branch of The United Steel Cos., Ltd., had been entirely rebuilt and enlarged from 80 to 100 tons capacity and was in production. Thus ended a major reconstruction programme which began early in 1953, and which was carried out with a loss in steel production directly attributable to the conversion of only 0·25% over the three-year period involved, which was, of course, more than offset by the steady rise in total output as each enlarged furnace came back into operation. This considerable achievement was made possible by careful advance planning, and by close co-operation and teamwork between maintenance and production personnel. Production at the Templeborough melting shop, which amounted to 594,027 ingot tons in 1952—the last full year before the reconstruction work began—rose to 729,171 tons in 1955 and is expected to reach 800,000 tons this year.

Installing New Cranes

At the beginning of 1953, the quarter-mile long Templeborough melting shop—the largest cold metal shop in Europe—contained fourteen open hearth furnaces of 80 tons capacity each, served by four 100-ton ladle cranes in the casting bay. Because of the increased volume of steel and slag to be handled from 100-ton capacity furnaces, it was necessary to instal 150-ton cranes, which in turn called for a complete renewal of the crane track girders. As the furnace conversions proceeded, the new cranes were erected in succession and the old ones dismantled, the programme being phased to ensure that the growing furnace capacity was always matched by the requisite crane-handling capacity.

Furnace Conversion Details

Average time taken to reconstruct each furnace, from tapping the last melt to relighting, was about nine weeks, including the installation of new straight-through Blaw Knox valves with single checkers. Full use was made of mechanical handling equipment to speed up the process of removing the old brickwork and bringing up supplies of new material. Altogether, 3,000 tons of steel and nearly 10 million refractory bricks were used in the conversion programme. The enlarged furnace hearths are 25 in. thick, consisting of a 1 in. layer of firebrick laid on steel plates, followed by 12 in. (four courses) of Dolofer brick and 12 in. of rammed dolomite. Each furnace has a bath area of 484 sq. ft.

Nine of the furnaces are oil-fired, four are on creosote pitch, and one is maintained on producer gas for experimental purposes. Fuel oil can be used as an alternative to creosote pitch on the four furnaces concerned, according to fuel availability. Twenty-one shifts per week are worked in the Templeborough melting shop, twelve furnaces being in operation at any one time, the remaining two being down for routine repairs and relining.

Crane Track and Cranes

The crane track girders, which involved 1,350 tons of steelwork, were designed and fabricated within the United Steel group by whe United Steel Structural Co., Ltd. The four new 150-ton ladle cranes are fitted with 25-ton auxiliary hoists, air conditioned control cabins and a telephone system linked with the teeming stage, these special features being the result of co-operation with The Wellman Smith Owen Engineering Corporation, Ltd., The Visco Engineering Co., Ltd., and The British Thomson-Houston Co., Ltd.

New Fuel Oil Applications

(*Continued from page 202*)

furnaces, tunnel kilns, glass melting furnaces, boilers, etc., and for firing gas works' horizontal retorts.

It is claimed that metals are less susceptible to damage from products of combustion when the oil is handled by this gasifier (or two stage combustion device as it is regarded by some) than when conventional oil burners are used. Tests at present being carried out will probably confirm these views.

General view of the new locomotive

New 400 h.p. Diesel-Electric Locomotive

Yorkshire Engine Company Introduces the Janus

BUILDERS of steam locomotives for railways and industrial users all over the world since their formation in 1865 at the Meadow Hall Works, Wincobank, Sheffield, Yorkshire Engine Co., Ltd., first began development on a diesel model in 1948. This work was carried out in collaboration with The British Thomson-Houston Co., Ltd., with the primary aim of producing a locomotive that would meet the needs of heavy industrial users. Equipped with B.T.H. electric transmissions and Davey Paxman diesel engines, 275 h.p. and 400 h.p. versions of this locomotive have been in service for over five years, and have established themselves in their own field.

The latest addition to Yorkshire Engine Company's range—the Janus* diesel-electric shunting locomotive—was again developed in collaboration with The British Thomson-Houston Company, and is being produced in 200 h.p. and 400 h.p. versions. Both locomotives are fitted with Rolls-Royce diesel engines and B.T.H. transmission, and are complementary to each other in that the equipment of the 400 h.p. model merely duplicates that of the less powerful locomotive, e.g., there are two 200 h.p. diesel engines instead of one.

By adopting the comparatively new 200 h.p. Rolls-Royce oil engine, which is in the automotive range, the Janus is provided with an engine generator set considerably smaller than is typical in installations of this horse-power. This has important implications: it reduces both first cost and maintenance, and enables a smaller bonnet to be fitted, thus improving visibility from the locomotive cab. Excellent visibility in all directions is indeed a special feature of the Janus; probably no other shunting locomotive available to-day gives the driver such a good all-round view, facilitating operations—and improving the safety factor—in crowded industrial surroundings.

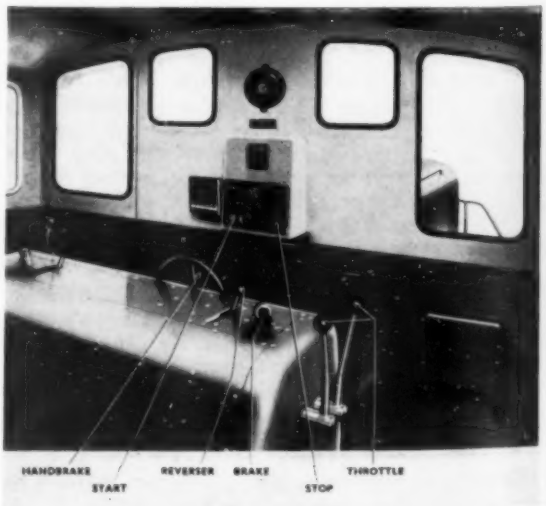
The 400 h.p. locomotive is usually built as an 0–6–0 type for any gauge from metre to 5 ft. 6 in., with reduction gear suitable for railway or industrial shunting requirements. All models built for use in this country are, of course, standard gauge.

* Janus, a celebrated Roman deity, is traditionally represented with two heads facing in opposite directions. The name is, therefore, most appropriate for a locomotive which looks the same at both ends.

Leading particulars of the locomotive are as follows:—

Weight	48 tons
Tractive effort at start	30,000 lb.
Speed at continuous rating	8 m.p.h.
Tractive effort at continuous rating	13,100 lb.
Maximum permissible speed	23 m.p.h.
Oil engines: super-charged Rolls-Royce C.6.SFL.	Two
Diesel engine rating at 1,800 r.p.m.	400 h.p.
Gear ratio	22·85 : 1
Wheel base	11 ft.
Wheel diameter	3 ft. 8 in.
Can negotiate curves	120 ft. radius
Type of axle boxes	Plain bronze or roller bearings
Brake equipment	Westinghouse straight air
Fuel tank capacity	400 gallons

The Janus follows the conventional rigid frame design, composed mainly of steel sections, and, as most of the weight is in the under frame, its strength is superior to a steam shunter and to most other types of diesel



Interior of driving cab showing controls

locomotive. The engine generator sets are mounted on resilient supports; there is no direct connection—other than electrical—between them and their traction motors, which hang on the outside pairs of wheels. The bonnets enclosing the power units consist of two sections, each of which, being small and light, is easily removed for maintenance purposes.

The driving cab is centrally placed, with doors opening on to diagonally opposite platforms accessible from the front and rear buffer platforms. The control desk in the centre of the cab is positioned to allow the driver considerable freedom of movement without loss of visibility. Control is effected by means of a throttle, which is directly connected to the two engine governors and also operates the main contactors; a reverser mechanically interlocked with the throttle; and a brake handle. All the controls are duplicated at either end of the desk.

It is impossible to overload the diesel engines, because the generator characteristics adjust the speed of the locomotive to suit the tractive effort required. This system of control provides continuous and entirely smooth variation of locomotive speed and tractive effort between standstill and full horse-power, simply by varying the engine speed. Unlike diesel locomotives fitted with other types of transmission, the fullest utilisation of horse-power is achieved. When limited horse-power is required for light duties, one engine generator set can be shut down.

The wheels of the new locomotive are coupled together, and overhung springing is provided in the axle boxes; the latter can be equipped with either plain or roller bearings. A 24-cell battery is used in series for starting the engine, and in parallel for lighting and for the cab heater ventilating fan. Fuel tanks holding 400 gallons are combined with the platforms, and have sufficient capacity for about one week's normal operation on two shifts; varying load factors and degrees of utilisation will, however, cause corresponding fluctuations in fuel consumption. Orthodox side buffers, Gedges hooks and three-link chains are fitted as standard equipment, but the special buffing and drawgear required by many industrial users can also be supplied, or screw couplings and the train braking equipment usually installed for main line railway locomotives.

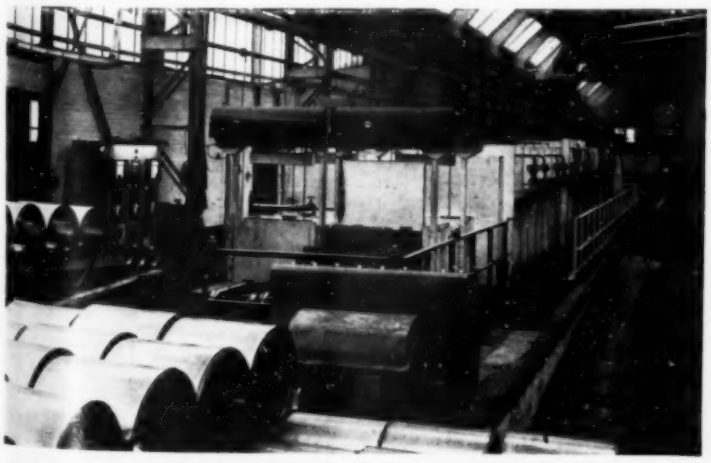
In addition to orders from the iron and steel industry, Yorkshire Engine Company have already obtained a substantial order from the Port of London Authority for the Janus diesel-electric locomotive, and considerable interest has been shown by other industrial users.

Automatic Heat Treatment of Coiled Brass Strip

G.W.B. Installation at I.C.I. Witton Works

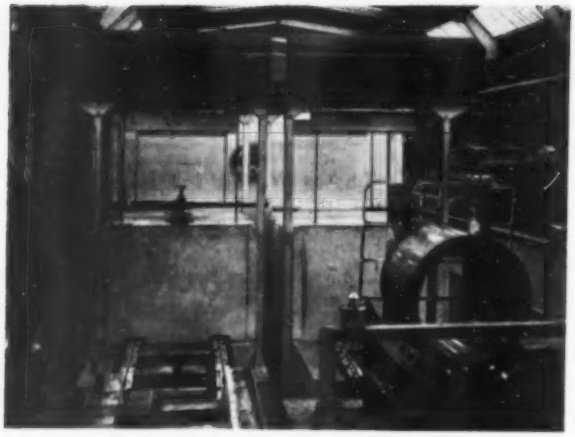
THE word automation is now being heard on an ever increasing scale in industry generally and has, up to the present moment, largely been used for referring to automatic processing of metals during fabrication without resort to manual handling. A series of manipulations and forming processes is carried out by means of transfer mechanisms so that a predetermined number of operations is followed through by means of sequence control systems. An interesting parallel to the development can be seen in the new electric furnace which has been supplied and installed in the Witton Works of Imperial Chemical Industries, Ltd. (Metals Division) by G.W.B. Furnaces, Ltd., of Dudley.

This furnace is of the electric resistance heated type, and is used for annealing coiled brass strip for the purpose of softening between rolling operations. The installation is of the walking beam design in which the coils are lifted for a few inches off the fixed portion of the furnace hearth by means of moving beams which then move forward and drop once more just below the fixed hearth level, and return to continue the cycle once more. The movement of the beams is arranged to be as near to rectangular as possible, and is effected by two separate motor mechanisms, one for vertical and one for horizontal movement. This method is found to be considerably superior to the eccentric cam method, which tended to subject the charge to abrasive action when being lifted from and lowered onto the fixed portion of the furnace hearth. This feature becomes quite pronounced in the case of relatively long furnaces such as the unit now being described, in shich the length of moving beam is nearly 50 ft.



General view of the furnace from the charging and discharging end.

From a plan view the furnace is U-shaped, comprising an ingoing and outgoing beam set side by side so that the charge and discharge points are adjacent, while change in travel direction of the charge is effected by means of a transfer car mechanism inside the furnace at the bottom of the "U." The main heating section of the furnace consists of a twin



View of charging and discharging end of furnace, showing coil manipulator.

chamber with a divided central wall, for the purposes of efficient air circulation, the length of this double section being 35 ft. The furnace wall, roof and hearth are lined with refractory fire-brick backed with graded insulation, while the fixed hearth of the furnace, which supports the coils when they are temporarily static, is capped with heat resisting steel. Nickel-chromium strip heating elements are arranged on the wall faces and roof, while heavy inverted V-section heating elements are fitted in the hearth. In order to achieve maximum heat transfer from the elements to the charge, a series of centrifugal fan units is fitted in the roof of the heating chamber, five fans on either side.

As a continuation to the double heating chamber, a fully bricked and insulated recuperative chamber assists in achieving the highest possible thermal efficiency, since heat is taken up by the ingoing coils from the outgoing charge. Along the outgoing section of the recuperative chamber, a series of centrifugal fans is fitted to assist in heat transfer from the hot to the cold coils.

Finally, at the charge and discharge points are fitted short entrance and exit chambers, with air or atmosphere locks in the form of lifting metal doors. In the exit chamber, high pressure water sprays are provided for final cooling. To indicate the degree of recuperation obtained, it can be stated that the ingoing coils reach a temperature of approximately 250° C. before entering the actual heating chamber, while electricity consumption is around 80 kWh./ton when heating up to 550° C.

The coils being processed weigh approximately 960 lb. each, and are usually 63/37 or 70/30 brass: the gauge is of the order of 0·120 in. or 0·160 in., the strip width being 24½ in. An output of 12 coils per hour is obtained, which amounts to a weight of 5·15 tons per hour. The furnace is designed for a maximum temperature of 850° C., while the normal working range lies between 550–600° C. The rating of 603 kW., arranged in nine independently controlled zones, is evenly distributed over the 3-phase 50 cycle supply. An additional 150 kW. is provided in the bricked section of the ingoing side of the recuperative chamber.

At this point, it would seem advisable to clarify the full progress of the charge into and out of the installation as a whole. Firstly, the coils are received from the preceding rolling operation down an inclined conveyor the axes of the coils being in the horizontal position. On reaching the manipulator situated at the front of the furnace, the coils are up-ended, so that the axes are vertical, onto a short slat conveyor section into the entrance chamber, through the atmosphere lock outer door. By means of a sequence control mechanism, the coils are passed through the inner door of the lock chamber and the ingoing beam then lifts them from the conveyor to start their journey through the furnace itself. At the bottom end of the furnace, a hydraulically operated transfer car moves the coils across onto the outgoing beam, all these movements being effected automatically. The sequence of operations is then repeated, only in the reverse manner, so that the outgoing beam places the coils onto the conveyor in the discharge chamber. When the exit door opens, the manipulator moves across and extracts the charge, and upends the coils so that their axes are once more horizontal. The coils are then transferred to a gravity conveyor to await subsequent re-rolling. The object of moving the axes from the horizontal to the vertical position when inside the furnace is to permit the air flow induced by the centrifugal fans to pass through the centre of the coils, thus achieving the best possible heat transfer.

As has already been indicated, all these movements and operations are carried out by means of an automatic sequence control arrangement, and only one operator is required for the whole of this heat treatment process.

Babcock Form New Division

Babcock & Wilcox, Ltd., announce the formation of a Materials Handling Division, which will co-ordinate in one group the various functions hitherto performed by separate departments. The new division will deal with all types of materials handling, including conveyors, together with Hydrojet and Hydrovac ash and dust handling plant and a new low pressure pneumatic Fly Ash handling system, but not with cranes or furnace-charging equipment, which will still be the province of the Crane Department, as at present. The new division will be officially formed in June, and will be accommodated at Lynton House, Tavistock Square, W.C.1 (tel. EUSton 4321).

The manager of the new division will be Mr. F. S. Stent, at present a director of the Marco Conveyor and Engineering Co., Ltd., well known to the industry for his activities in connection with the Mechanical Handling Engineers Association. Mr. R. A. Taylor, hitherto in charge of the Conveyor Department of Babcock & Wilcox, has been appointed Chief Technical Advisor to the new division. Mr. Taylor is well known to the industry for his developments in the tandem-driving of heavy belt conveyors, and on the avoidance of the segregation of coal during handling.

Aluminium Plant Alarm

An automatic signalling equipment to avoid power waste and damage during the making of aluminium has been made in Hungary and installed in the Inota Aluminium furnaces. The equipment is fitted to the electrolysing baths, and shows when the aluminium content falls to a dangerously low level. A lamp and an amplified sound signal are used to indicate this condition. The lamp continues to burn until alumina is added to rectify the bath.

NEWS AND ANNOUNCEMENTS

British Commonwealth Welding Conference

An invitation is extended by the Institute of Welding to all those in the British Commonwealth who are interested in the welding processes and their applications to attend The First British Commonwealth Welding Conference to be held in London and Saltburn-by-Sea, Yorkshire, from June 17th–29th, 1957. The objects of the conference are to exchange information on the present technical position of welding processes and their main applications within the Commonwealth; to consider means of improving the exchange of technical information about welding among the countries of the Commonwealth; and to emphasise the importance of the contribution which welding can increasingly make to the development of modern engineering production. The conference will open in London on Monday, June 17th, 1957, and will remove to Saltburn-by-Sea on Sunday, June 23rd, returning on Thursday, June 27th, to London, where it will close on Saturday, June 29th. An outline programme and enrolment form will be distributed at the end of October, 1956, to those who apply for them to the Secretary, Institute of Welding (C.W.C.), 2, Buckingham Palace Gardens, London, S.W.1, England. Ten sessions of three hours each will be allotted to the discussion of papers and the Organising Committee invites offers of papers for presentation at the conference. All these papers will be preprinted in full or in summary form, and will be distributed to members before the Conference. Offers to contribute papers should be made on a form obtainable from the Secretary, and must be received at the Conference Office by August 1st, 1956. For the guidance of authors, a list of subjects which it is intended to discuss may be obtained from the Secretary.

Society of Instrument Technology, Ltd.

The Society of Instrument Technology, Ltd., was founded in 1945, and today the membership of all classes has reached nearly 1,400. This number has been built up largely through the untiring efforts of Honorary Officers, without the help of either a full-time staff or permanent headquarters in London. Because of the continued growth of the Society and its activities, and the increasing recognition of the need for automation in industry, the Council has been conscious for some time that not only would the interests of members be best served by providing full-time staff with office accommodation, but that such staff would relieve some of the burden on the Honorary Officers.

Through the courtesy of the Council of the Scientific Instrument Manufacturers' Association of Great Britain, Ltd., an office has been taken at 20, Queen Anne Street, W.1 (LANgham 4251/2), and a full-time secretary and clerical staff engaged. The secretary is Commander A. A. W. Pollard, D.S.C., R.N. (Retd.), who has recently left the Navy after more than 31 years' service in the Executive Branch. He has had a varied career, having served in ships varying from destroyer to aircraft carrier. In more recent years, he has held a number of staff and administrative appointments, and been much concerned in Research and Development. The office in Queen Anne Street is now functioning and all correspondence except that which affects the editorship of the Society's *Transactions* should be addressed accordingly. Dr. Harold Moore, C.B.E., has kindly consented to remain Honorary Editor for the time being.

The Society of Chemical Industry

Among the arrangements made in connection with the 75th Annual Meeting of the Society of Chemical Industry are visits to a number of factories and research organizations in the London area. The week of the meeting, which is from Monday, July 9th to Saturday, July 15th, begins with a reception on the Monday evening at Guildhall by the chairman, Sir Charles Dodds and Lady Dodds. The Annual General Meeting will take place on the Tuesday. The places to be visited by members of the Society during the week include the Paint Research Station at Teddington, the National Institute for Medical Research, the Central Electricity Authority (Bankside Generating Station), Glaxo Laboratories, the Isle of Grain refinery of Shell-Mex and B.P., and the Atomic Energy Research Establishment at Harwell. The annual dinner will be held on the Wednesday at the Dorchester Hotel.

Special Libraries' Conference

The theme of the Special Libraries Association Convention, to be held Pittsburgh from June 4th–7th, 1956, is "Putting Knowledge to Work," and "Creative Thinking" is the subject for the Metals Division Programme on Monday afternoon, June 4th. The papers to be presented at this session, which will be presided over by Mrs. Virginia Seidell, Librarian, International Nickel Company, New York, include "Characteristics of Creative Thinking—with Examples of its Use," by Robert W. Kubasta, Supervisor, Engineering Training, Carrier Corp., Syracuse, New York; "Some Creative Writing Opportunities Open to Metals Librarians," by Irving H. Jenks, Head, Division of Publications and Documents, Aluminium Laboratories, Ltd., Kingston, Ontario, Canada; and "Creative Thinking in Metals Libraries—Implications for Librarians," by Allen Kent, Associate Director, Center for Documentation and Communications Research, School of Library Science, Western Reserve University, Cleveland, Ohio.

Welding Exhibition in Scotland

An exhibition to show the progress made in the development of welding equipment to meet the ever increasing needs of industry, will be held in Glasgow at the premises of the Scottish Electricity Board, in Hawick Street, Yoker, from May 24th to June 1st.

The exhibition, which includes demonstrations, is organised by Quasi-Arc, Ltd., and there will be special sections devoted to manual welding equipment, automatic equipment, inert-gas processes and manipulative equipment. The Sigma spot welder for making spot welds in mild steel from one side only, will be demonstrated, and parallel welding with the Unionmelt process will be shown, together with a new metal rectifier welding

set—MR 350. The two manual electrodes, Vertispeed (recommended for positional welding of oil storage tanks and gas golders) and Vordian (an all-positional, general purpose mild steel electrode) will also be on view.

Welding Engineers' Course

QUASI-ARC, LTD., of Bilston, Staffordshire, organise from time to time special courses for welding engineers supervisors and inspectors. The courses consist of practical training, lectures and demonstrations on arc welding processes, classification of electrodes, arc welding equipment, distortion, weldability of ferrous and non-ferrous metals, Sigma welding, automatic arc welding, radiographic examination of welds, design, costing and supervision. The practical training covers welding of various types of joint, techniques, and testing and examination of welds. The next course, which will last for three weeks, will commence on June 11th, 1956, and there will be a further course on August 27th. Full details and application forms for enrolment will be sent on request.

Irradiation Effects in Solids

UNDER the auspices of the Metal Physics Committee of the Institute of Metals, PROFESSOR R. SMOLUCHOWSKI, of the Carnegie Institute of Technology, Pittsburgh, at present Visiting Professor of Physics at the Sorbonne, Paris, will lecture on "Some Recent Studies of Irradiation Effects in Metals and Other Solids." The lecture will be delivered in the Weir Hall of the Institution of Naval Architects, 10, Upper Belgrave Street, London, S.W.1, at 6-30 p.m., on June 13th, 1956. Visitors will be welcome; tickets of admission are not required.

Federation of Light Metal Smelters

THE FEDERATION OF LIGHT METAL SMELTERS announces that at the Eleventh Annual General Meeting of Members held on April 12th, 1956, Mr. B. ENDLAR (John Dale, Ltd.) was appointed chairman for the ensuing year, in succession to Mr. P. G. HALLIWELL (J. Frankel (Aluminium), Ltd.). Mr. R. HAHN (B.K.L. Alloys, Ltd.), was appointed vice-chairman. The new council consists of the chairman, the vice-chairman, the retiring chairman and Mr. F. FARENDEN (The Eyre Smelting Co., Ltd.). Mr. R. HOPKINS (John E. Moore, Ltd.) and Dr. J. JAKOBI (International Alloys, Ltd.).

A.E.I. Lamp and Lighting Co., Ltd.

A NEW company, the A.E.I. Lamp and Lighting Co., Ltd., has been formed to market the lamp and lighting products of The British Thomson-Houston Co., Ltd., The Edison Swan Electric Co., Ltd., and The Metropolitan-Vickers Electrical Co., Ltd. The brand names Mazda, Ediswan and Metrovick, associated with the lamp and lighting products of the three companies, are being retained.

By amalgamating the distributive resources of the three companies, it has been possible to provide a speedier and more comprehensive service to customers. The British Isles has been divided into seven regions with headquarters in London, Birmingham, Glasgow, Leeds, Manchester, Cardiff and Dublin. In each region is a central warehouse capable of carrying several months' stock of the lamp and lighting products of all three brand names.

These warehouses in turn feed area stores strategically placed to provide rapid deliveries to customers. Members of the Board of the new Company are drawn from the constituent companies, the Chairman being Mr. E. H. BALL. The Joint Managing Directors are Mr. V. C. H. CREER, who will be concerned with the commercial interests of the new company, and Mr. S. R. EADE, who will be responsible for engineering and manufacture. Mr. W. A. RENAUT is Comptroller and Secretary, and the other Directors are Mr. N. V. EVERTON, Deputy Chairman; Mr. W. W. VINSEN; Mr. L. J. DAVIES; Mr. E. S. LITTLE; Mr. F. E. C. MILLER; and Mr. T. J. DAGLEY.

Royal Society Delegation to Moscow

AT the invitation of the Academy of Sciences of the U.S.S.R. the Royal Society is sending a delegation to Moscow under the auspices of the Soviet Relations U.S.S.R. the Royal Society is sending a delegation to Moscow under the auspices of the Soviet Relations Committee of the British Council. The delegation, leaving on May 18th, 1956, will spend a fortnight in the U.S.S.R. visiting scientific institutions.

LORD ADRIAN, O.M., the immediate Past-President of the Royal Society will lead the delegation, and other members are: LADY ADRIAN; DR. H. G. THORNTON, Foreign Secretary of the Royal Society and Head of the Department of Soil Microbiology at Rothamsted Experimental Station; MISS M. L. CARTWRIGHT, F.R.S., Mistress of Girton College, Cambridge; PROFESSOR J. H. GADDUM, F.R.S., Professor of Pharmacology in the University of Edinburgh; PROFESSOR J. M. ROBERTSON, F.R.S., Professor of Chemistry and Head of the Chemical Laboratories of the University of Glasgow; PROFESSOR M. STACEY, F.R.S., Professor of Chemistry in the University of Birmingham; and DR. D. C. MARTIN, Assistant Secretary of the Royal Society.

International Congress of Surface Activity

THE first International Congress of Surface Activity was held in Paris in 1954. The second Congress will be held in London from April 8th to 12th, 1957, with Lord Brabazon of Tara as the President of Honour, and Professor Sir Eric Rideal as the President. An organizing committee has been set up under the chairmanship of Dr. Leslie H. Lampitt, and with Sir Charles Dodds as honorary treasurer and Lt.-Col. Francis J. Griffin as honorary secretary. Membership of the Congress is open to all interested persons on payment of the membership fee of £4. It is hoped to issue a detailed programme in the near future and all enquries should be addressed to: The Honorary Secretary, Second International Congress of Surface Activity, 14, Belgrave Square, London, S.W.1.

New Australian Order for Davy-United

DAVY AND UNITED ENGINEERING CO., LTD., of Sheffield, have secured another large contract for the expanding steel industry in Australia. Placed by Australian Iron & Steel, Ltd., this order is worth nearly half-a-million pounds, and covers the supply of extensive roller tables for a new slabbing mill which the Australian Company are installing at their Port Kembla Works in New South Wales. In all, Davy-United will be supplying about 4,800 tons of new machinery for this contract, which is due for delivery early in 1957.

RECENT DEVELOPMENTS

MATERIALS : PROCESSES : EQUIPMENT

New Continuous Electrode

QUASI-ARC, LTD., announce the addition of Firmec to their range of continuous electrodes for use on Fusarc automatic welding machines. The new electrode is designed for the welding of mild steel in the flat position, and is particularly suitable for fillet welding and single pass butt welds, in thicknesses from $\frac{3}{16}$ in. to $\frac{3}{8}$ in. High welding speeds are possible with this electrode, since a larger size than normal can be used for any given fillet weld size. This special feature also results in reduced material costs and enables Firmec electrode to be used for making the smaller sizes of fillet welds where appropriate.

The welds deposited with the new electrode have a very smooth appearance and the slag detachability is good. They are recommended for shipbuilding and general engineering applications, and particularly for work where high quality finish is essential. Firmec electrode is made in sizes 12 s.w.g. to 4 s.w.g., and complies with B.S. 639 : 1952. It is approved by the Ministry of Transport and Lloyd's Register of Shipping for welding mild steel in the flat position.

Quasi-Arc, Ltd., Bilston, Staffs.

Soldering Aluminium Alloys

THE problem of soldering aluminium has been of interest for many years, difficulty of application and corrosion resistance presenting serious problems. Present soft soldering technique usually relies on heavy and expensive soldering tools, whether mechanically or electronically operated, and the 90% tin, 10% zinc alloy is one of the easiest to apply and commonly used solders. Tiltman Langley, Ltd., have, under a Ministry of Supply development contract, made an investigation into aluminium soldering, and although the programme of work is still going on, a soldering tool has been developed which is easily manipulated, light and cheap, and capable of being used for the fluxless soldering of aluminium with any normal solder used for this purpose. The possibilities of soldering aluminium at 250° C. have also been investigated with a solder developed by Tiltman Langley for making corrosion resistant joints in high-strength aluminium alloys or cold-worked aluminium, without appreciably weakening the materials being joined.

The equipment used comprises a hand tool and an electric hot plate for raising the work to the soldering temperature. The technique is to apply the solder and lightly brush the surface being tinned with a guarded refractory brush on the tool, any of the usual cleaning techniques having been previously applied to the aluminium ; no flux is used. The surfaces to be joined after tinning are placed together, and a neat fillet of solder produced by sweeping through the molten solder with the refractory brush. It is claimed that this implement, used manually or mechanically, is more universal in its application than other soldering tools for use on aluminium, and that it is also less damaging to the surface than other tools.

The Tiltman Langley solder, which has been subjected to salt spray and humidity tests, has shown good corrosion resisting properties in aluminium soldered joints. It also provides good mechanical properties. After being raised to a soldering temperature of 250° C. for a short time, no appreciable loss of mechanical properties is experienced by the majority of aluminium alloys. A shear strength of $2\frac{1}{2}$ tons/sq. in. is obtained in such soldered joints.

Patents for both soldering tools and solder compositions have been applied for.

Tiltman Langley, Ltd., Redhill Aerodrome, Redhill, Surrey.

Dry-Chemical Fire Extinguisher

A NEW pressure-operated dry-chemical fire extinguisher, which weighs less than 10 lb. when fully charged, is now being marketed by Pyrene. It has been designed to meet the need for a small, yet powerful fire smothering unit to deal with outbreaks involving petrol, oils, paints, spirits, solvents, greases, etc. It can also be used with safety on fires involving electrical equipment.

Charged with 5 lb. of dry chemical powder, the extinguisher is pressurised with nitrogen up to 150 lb./sq. in., although it will still operate satisfactorily at pressures as low as 100 lb./sq. in. The pressure is constantly recorded on a gauge embodied in the head of the operating valve, a feature which provides the operator with an instant check on the condition of the extinguisher. The model is offered with either a pistol-grip or squeeze-grip operating head, both types providing speedy, accurate control over the discharge of dry chemical which can be turned on or off at will. A specially designed nozzle projects the contents in the form of a fan-shaped jet with an angle of over 30°, smothering the fire in a thick blanket of dry chemical powder. The extinguisher has a range of about 8 ft.

The design of the extinguisher enables it to be recharged after use simply by topping up or refilling the cylinder with 5 lb. of dry chemical. If nitrogen is not available, the extinguisher can be pressurised from a garage or factory air line or from an efficient motor car foot pump with dry air. Pyrene portable dry chemical extinguishers are also supplied with a capacity of 25 lb. of dry chemical, while there is a trolley unit available having a capacity of 150 lb.

The Pyrene Co., Ltd.

Laboratory-Size Endothermic Generator

A NEW laboratory-size endothermic generator is the most recent addition to the extensive lines of controlled atmosphere processing equipment produced by Ipsen : it will be ideal for the small scale heat treatments usually required in the laboratory or tool room heat treatment department. Rated output is approximately 150 cu. ft./hr. of prepared atmosphere gas, but this output can be increased by approximately 50% when required.

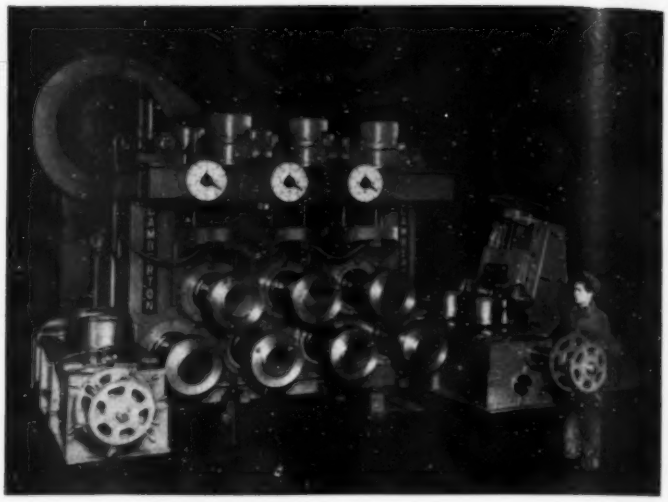
Although the generator is specifically designed for use with the Ipsen RT-25 laboratory furnace, it can be used with any controlled atmosphere furnace of proper size. The generator is housed in a compact cabinet with operating instruments and controls conveniently located in front.

Ipsen Industries, Inc., 715, So. Main Street, Rockford, Illinois, U.S.A.

Roller Straightening Machine

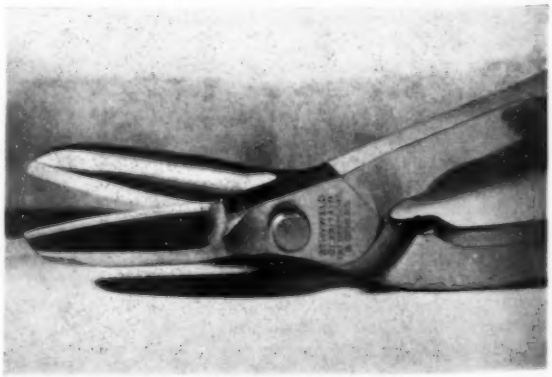
STEELWORKS engineers will be interested to hear that Lamberton have introduced a new roller-straightening machine—the 26 in.—which is a smaller version of their well-known 53 in. straightener. The new machine is of welded steel construction, robustly built to withstand the heavy stresses developed in the straightening process. Whereas the bigger machine can handle all the heaviest sections and rails rolled in the U.K., the smaller machine is meant to take 12 × 5 in. joists and 50 lb./yd. rails. The two banks of rolls are at 26 in. horizontal centres, three (adjustable) rolls above and four (fixed) below. The rolls are carried by horizontal spindles, and the overhung design entails the use of generously proportioned spindles and roller bearings to prevent excessive deflection. Axial adjustment is provided, and the distance between the upper and lower rollers can be altered to admit sections of varying size. Guide rollers on vertical spindles at the ingoing and outgoing side are driven from the first and last spindle drives, so that their speed is that of the straightening rolls: they are adjustable to handle various sizes. Besides guiding the piece on to the straightening rolls, they provide additional drive to the sections. The whole machine is driven by an electric motor through a reduction gear box external to the machine frame. The output shaft from the gear box drives, through a flexible coupling, a pinion in the main frame. From this a train of spur gears distribute the drives to the four spindles. Two 53 in. straighteners and one 26 in. are being built for the National Steel Works in Spain, two 26 in. for Dorman Long, Cleveland, and one 53 in. for the new Lackenby Works of Dorman Long.

Lamberton & Co., Ltd., Coatbridge, Scotland.



Tinsman's Snips for Tough Material

TINSMAN'S snips to cut stainless and tough alloy steel sheet are now being produced by Thomas R. Ellin (Footprint Works), Ltd., in conjunction with Edgar Allen & Co., Ltd. They incorporate cutting edges of 18% tungsten high speed steel, deposited by the Athy-weld patent deposit-welding process. The cutting edges



are scientifically hardened and tempered, and the general design of the tool has been strengthened on both the blades and the shanks. Production at the moment is confined to snips in 13 in. and 15 in. sizes, but other designs will be manufactured in due course. Known as Footprint brand Red Tip snips, these tools (patent applied for) are expected to be the forerunners of a variety of tools of a similar nature, and should be welcomed by sheet-metal workers generally.

Thomas R. Ellin (Footprint Works), Ltd., Sheffield.
Edgar Allen & Co., Ltd., Imperial Steel Works, Sheffield, 9.

CURRENT LITERATURE

Book Notice

CREEP AND FRACTURE OF METALS AT HIGH TEMPERATURE

Proceedings of a Symposium on Creep and Fracture of Metals at High Temperature held at the National Physical Laboratory, June, 1954. 420 pp. Published by H.M. Stationery Office for Department of Scientific and Industrial Research. 30s. By post 31s. 5d.

In the August, 1954, issue of *Metallurgia*, there appeared a brief account of the papers presented at a Symposium on Creep and Fracture of Metals at High Temperature, held at the National Physical Laboratory from May 31st to June 2nd, 1954. The three-day symposium was attended by many leading scientists from fifteen countries, including Australia, France, Germany, Great Britain, Japan, U.S.A., and U.S.S.R., and the papers and discussions reflected the growing interest in the development and use of creep resisting alloys, and recorded the advances made in understanding the mechanism of creep processes, and drew attention to the implications of these phenomena. The Proceedings of the Symposium have now been published in a volume which includes the twenty-two papers and a report of the contributions to the discussions. As far as possible, revisions suggested by authors to their papers as presented have been included, and it is believed that no revision of scientific significance has been omitted. In some instances, new material has been added.

As Dr. N. P. Allen, Superintendent of the Metallurgy Division at N.P.L., pointed out in his introductory paper, the object of the symposium was to assess the progress that had been made on both plastic deformation and fracture. This is reflected in the titles of the papers which are presented in four sections covering, respectively, deformation in simple materials ; creep resistance of complex materials ; the theory of fracture ; and work on tertiary creep and fracture.

STEEL FOUNDRY DUST CONTROL AND VENTILATION

Proceedings of Conference held at York, October, 1955. 98 pp. inc. numerous illustrations. Published by The British Steel Castings Research Association, Broomgrove Lodge, Sheffield, 10. 42s.

This volume contains the eight papers presented to a conference organised by The British Steel Castings Research Association and held at York in 1955, together with reports of the discussions on them.

In opening the conference, Sir George Barnett, H.M. Chief Inspector of Factories, commented upon its timeliness in relation to the coming into force on January, 1956, of certain provisions of the Iron and Steel Foundries Regulations, 1953. Reports of his opening address and of his summing up at the end of the conference are included in the volume.

The papers presented were : " Dust Control on Stand Grinding Machines," and " Dust Control on Swing Frame Grinding Machines," by C. M. Stoch (B.S.C.R.A.) ; " Dust Extraction on the Pneumatic Chisel," by J. R. B. Lloyd (F. H. Lloyd & Co., Ltd.) ; " A Low Volume High Velocity Exhaust System," by W. B. Lawrie (H.M. Engineering Inspector of Factories) ; " Sampling and Assessment of Airborne Dust," by G. M. Michie (B.S.C R.A.) ; " Efficiency of Dust Collectors," by C. J. Stairmand (I.C.I., Ltd., Billingham Division) ; " Foundry Ventilation and Heating," by F. R. L. White (Brightside Heating & Engineering Co., Ltd.) ; and " Dust Control at Foundry Knock-Outs," by W. D. Bamford (B.C.I.R.A.).

WORKING METALS BY ELECTRO-SPARKING

By A. V. Nosov and D. V. Bykov (an abridged translation from the Russian). 66 pp. Published by H.M. Stationery Office for the Department of Scientific and Industrial Research. 5s. (by post 5s. 3½d.).

Electro-spark machining is one of the newer techniques for working metals, particularly metals and alloys of great hardness, in which the erosive effect of repeated electrical discharges between tool and workpiece is used instead of conventional metal-working tools to carry out the work required. The tool itself does no actual abrading but acts only as an electrode. It can be made easily and cheaply therefore from a soft metal such as brass, and no special treatment is required. The method can also be used for sharpening carbide tools with ease and safety without destroying their temper. An advantage of the technique is that it will produce holes of square, octagonal, star-shaped or any other required section. It is even possible to produce holes which curve along their longitudinal axes—an achievement impossible with ordinary drills.

This publication covers the physical laws governing the technique, the technological requirements for using the process and the results which can be obtained. A great deal of operating experience has already been obtained in Russian factories and the translation includes an outline of workshop procedure based on operations carried out in the workshops of industrial co-operative societies.

COLUMN TESTS ON SOME PROPOSED ALUMINIUM STANDARD STRUCTURAL SECTIONS

By R. E. Smith, M.A. A.D.A. Research Report No. 28. 41 pp., numerous tables and illustrations. Published by The Aluminium Development Association, 33 Grosvenor Street, London, W.1. 7s. 6d.

At the present time the only standard aluminium structural sections available to designers in Great Britain are those specified in B.S.1161 : 1951, 'Aluminium and Aluminium Alloy Sections.' In 1952 the Aluminium Development Association initiated an investigation into the possibility of introducing some new standard sections which would make more effective use of the advantages of the extrusion process. After consultation with various designers in aluminium, tentative proposals for several ranges of sections were put forward.

All the proposed sections incorporated root fillets and edge beads to provide increased resistance to elastic instability, and, as no theoretical work was readily available for these types of section, it was considered advisable to check their load carrying capacity by test. The present Report describes the tests applied to the following sections : light, and medium equal bulb angles ; unequal bulb angles ; light, and medium lipped

channels; lipped H-section. Results are discussed and conclusions drawn concerning the curves recommended for use as a basis of design.

Trade Publications

THE March, 1956 issue of *The Aluminium Courier*, published by the Aluminium Development Association, has as its theme "Roof Coverings." The contents include a general article on the subject, giving an indication of the extent to which aluminium has been adopted for this purpose and the way in which it is used. Details of sheeting profiles specially developed for roofing are briefly presented in another article, while a third describes the erection of an aluminium fully-supported church roof. Other features of the issue include reports on the Aluminium in Building Exhibition, and the Symposium on the Use and Welding of Aluminium in Shipbuilding, and a discussion of the revision of the British Standards for aluminium and its alloys.

ISSUE No. 38 of *Wiggin Nickel Alloys* contains a number of interesting articles on applications of nickel and its alloys. They deal with a wide range of subjects, including: selective weed killers; machines for measuring creep; developments in drip-feed gas carburising plant; nickel for caustic soda evaporators; Nimonic 90 springs in high temperature safety valves; immersion heaters; American high pressure heaters; and Monel brine tanks.

WE have received from G.W.B. Furnaces, Ltd., three leaflets covering the range of mains frequency induction melting equipment which the company is offering to the markets in Britain, the Commonwealth, and certain overseas countries. These furnaces, with which the Milan firm of A. Tagliaferri is associated, are of the channel type, and the three leaflets describe fully the models designed for melting cast iron, copper alloys, and aluminium alloys, respectively.

DARWINS, LTD., Tinsley, Sheffield, 9, have issued a fully illustrated brochure introducing Tru-process castings. Tru-process is an investment technique employing a high grade refractory material which will resist the attack of steels and other special alloys of high melting point. It has been used with success for the production of dies and moulds for the plastic and other industries. Castings may be produced directly from patterns of any convenient material, and, although the process is cheaper and quicker than the "lost wax" process, practically the same degree of accuracy is attainable.

WE have received from Talbot Stead Tube Co., Ltd., four new publications. One of these, published in French and German as well as English, outlines the activities of the company, which include the production of a vast range of tubing in carbon and alloy steels; tube fittings and components; and bright drawn, turned and ground bars; tube manipulation and fabrication. The remaining publications are: a stainless steel tube catalogue; a stainless steel fittings catalogue; and a table of steels for Metior stainless steel tubes.

BEMCO PUBLICATION 152A, entitled "SMZ Alloy as a Ladle Addition to Cast Iron," deals with the properties and uses of this material, which is essentially a balanced alloy containing silicon, manganese and zirconium. It exerts a strong graphitizing effect when used as a ladle addition in making cast iron. It is especially recommended for making high-strength grey iron; for improving mechanical properties; for reducing chill; for reducing wall sensitivity; and for improving chromium iron. Copies may be obtained from British Electro Metallurgical Company, A Division of Union Carbide, Ltd., Wincobank, Sheffield.

THE April, 1956, issue of *Instrument Engineer*, features articles on expansion thermometer systems; installation of power units; the history of the commercial metering of air, gas and steam by differential pressure; and of special metallurgical interest—instrumentation and automatic control of open hearth furnaces. *Instrument Engineer* (price 2s. 6d.) is published by George Kent, Ltd., Luton, Beds.

A LEAFLET recently issued by Sanderson Brothers & Newbould, Ltd., Attercliffe Steelworks, Newhall Road, Sheffield, deals with Celfor shallow hardening steel. This is a 1% carbon steel, notable features of which are the high hardness figures obtained on the case after quenching, and the uniformity of the depth of this hardness irrespective of the section down to $\frac{5}{16}$ in., at which point the hardness penetration is practically through. Details are given of working and heat treatment procedures.

AN instrument which has had a considerable impact on analytical practice is the Spekker absorptiometer, and an article in the February issue of *Hilger Journal* traces its development from an instrument designed for medical purposes in 1936. Other articles in this issue deal with X-ray diffraction equipment, and a spectrographic technique for measuring wear in engines which may achieve considerable importance during the next few years as a means of controlling the maintenance of large fleets of diesel locomotives.

WE have received from The Morgan Crucible Co., Ltd., a leaflet dealing with silicon carbide refractories. The special advantages of these materials are the mechanical strength, freedom from thermal spalling, resistance to abrasion and to attack by coal slags, and a thermal conductivity which is 5–6 times that of normal fireclay refractories. Triangle silicon carbide refractories are made in a variety of grades and standard shapes. Jointing cement and patching are also available.

LUBRICATION is to be regarded as one of the primary factors which govern the behaviour of diamond wire drawing dies. It can influence both the life of the die and the quality of the wire which the die produces. A booklet entitled "Lubrication in Wire Drawing," issued by the British Diamond Die Federation, Dickens House, 15, Took's Court, London, E.C.4, summarises the most modern practice in lubrication of diamond dies. For this purpose, the metals and alloys most generally drawn through diamond dies have been divided into four groups, each with its own characteristics.

THE British Gear Manufacturers' Association numbers among its members the principal British manufacturers of machine cut gears, enclosed gear drives and other power transmission equipment related thereto. Also associated are companies which manufacture machines or tools for cutting gears or carrying out finishing operations on gear teeth. The Association has recently issued a second edition of its Buyers' Guide, which includes details of the range of products of each member and associate-member of the Association. Copies may be obtained from the Association at P.O. Box 121, 301, Glossop Road, Sheffield, 10.

LABORATORY METHODS
MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC
INSTRUMENTS AND MATERIALS
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Electro-polishing and Electro-etching a Sintered Cobalt Alloy

By E. R. Perry, D.F.C., A.I.M.

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Because of its corrosion resistance, slight porosity and susceptibility to structural change on deformation, sintered Vitallium presents difficulties in preparation for microscopic examination. Details are given of techniques developed for polishing and etching electrolytically.

WORK has proceeded for a number of years on the manufacture of sintered high temperature alloys for gas turbine applications,[1-3] particular attention having been given to the alloy Vitallium (64% cobalt; 30% chromium; 6% tungsten). At an early stage of this work it was obvious that preparation of surfaces suitable for metallographic examination was troublesome. The difficulties were associated with the following factors:—

(1) The alloy has excellent corrosion resistance, and no solution was found which would give a uniformly etched surface. (The most suitable, applied by swab, was a solution of 1 part 100 volume hydrogen peroxide and 3 parts concentrated hydrochloric acid.)

(2) The method of manufacture used resulted in an alloy of 98·5% theoretical density. This degree of porosity was often sufficient to retain etchant which later exuded and pitted the surfaces.

(3) Abrasion polishing resulted in a deformed layer at the surface and this was accompanied by a structural transformation from face centred cubic to hexagonal close packed. It was thus doubtful whether metallographic examinations were being carried out on the alloy in the desired condition, so that techniques were sought which did not result in such surface layers.

In efforts to obtain a suitable surface, electrolytic treatments were examined. No record was found of any success in electro-polishing sintered alloys of this type, but this method of preparation seemed most likely to avoid the difficulties enumerated above. The object of this note is to describe the electrolytic treatments which proved acceptable, since this information may be useful to others working with this class of material.

Electro-polishing

A literature search revealed that there were several electrolytes[4-8] which might be suitable for this alloy. These, and variants based upon them, were fully investigated. Particular attention was devoted to different waveforms of electrical supply, variations in the voltage applied to the cell, position of the cathode in relation to the specimen, and the time needed for the operation. Only one of the solutions[8] examined was suitable, and optimum results were obtained with this under the following conditions:—

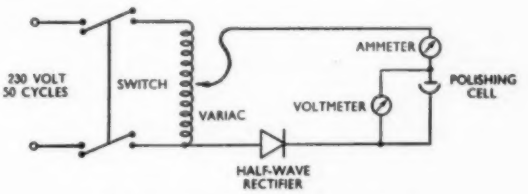

Fig. 1.—Electro-polishing circuit.

Surface Preparation.—Surfaces were ground through the usual range of emery papers to Durexsil grade 600A before polishing.

Electrolyte.—100 ml. perchloric acid (S.G.1·70)
142 ml. distilled water
758 ml. industrial methylated spirits

This solution was used many times. It should be stored in a stoppered bottle to prevent evaporation of the spirit.

Temperature.—Room temperature. The electrolyte was agitated and cooled to avoid high local temperatures and consequent explosive risks.[9, 10]

Cathode.—Strip of stainless steel or Vitallium. Best results were achieved when the cathode was vertically opposite and 25 mm. away from the specimen undergoing treatment.

Anode.—Throughout the experiments, the area of the specimens used was 1 sq. cm.

Supply.—The circuit used is shown in Fig. 1. It was found that half-wave rectified alternating current gave superior surfaces to waveforms[11-13] recommended for other metals and electrolytes.

Voltage.—The most satisfactory results were obtained when the P.D. across the cell was 48 volts during electro-polishing. (Polishing was achieved with all voltages in the range 12 to 60 volts, but while the metallic lustre of the alloy was somewhat better at lower voltages, pores were much larger.)

Current Density.—9 amp./sq. cm. The relation between current density and voltage is shown in Fig. 2.

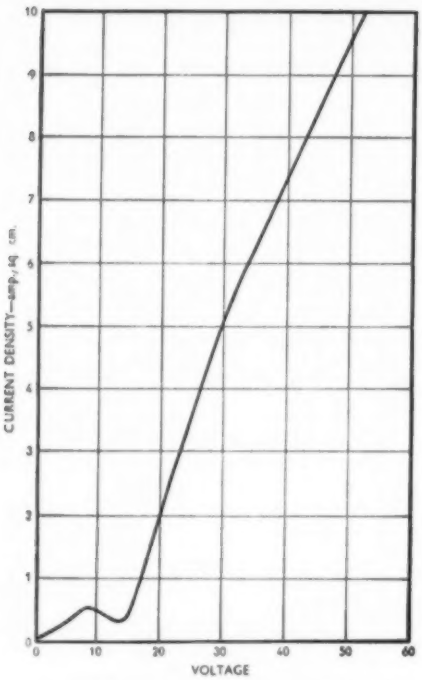

Fig. 2.—Voltage (in volts)/current density curve using specimens of 1 sq. cm. area.

Time.—3 seconds. Polishing time was very important, as was demonstrated in the following three simple experiments :—

(1) Figs. 3, 4 and 5 compare surfaces polished for 3, 10 and 15 seconds, respectively. It is evident that prolonged times resulted firstly in enlarged pores and finally in the development of rippled surfaces.

(2) Before polishing, the surfaces of two specimens were prepared with different grades of emery. Scratches resulting from 600A grit were removed in 3 seconds (Fig. 3). The second specimen had 100D grit scratches, and electrolysis was necessary for 15 seconds to remove them. The appearance was then similar to Fig. 4.

(3) Fig. 3 was compared with a specimen which had been polished at 20 volts ; electrolysis was necessary for 30 seconds to remove scratches, and the surface was similar to Fig. 5.

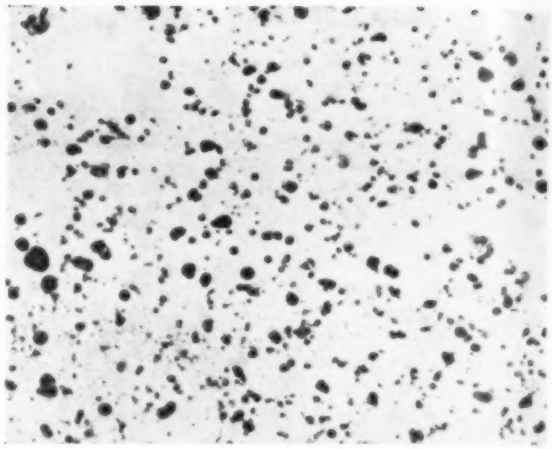

Fig. 3.—Electro-polished for 3 seconds at 48 volts and 9 amp./sq. cm. ×200

It was concluded from these experiments that the polishing conditions should be arranged so that specimens are polished for the minimum time, as otherwise pores are enlarged.

Mechanically and Electrolytically Polished Surfaces Compared

Fig. 3 is representative of a specimen produced using the best electro-polishing practice found with this electrolyte. For comparison, Fig. 6 is included to illustrate a surface which was obtained by abrasive methods. It is evident from Fig. 3 that, in general, pore sizes are slightly larger than in Fig. 6, but the distribution of porosity is similar. It was not possible to determine

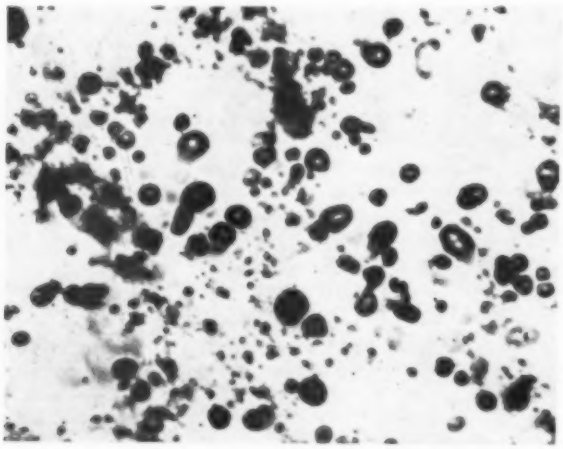

Fig. 4.—Electro-polished for 10 seconds at 48 volts and 9 amp./sq. cm. ×200

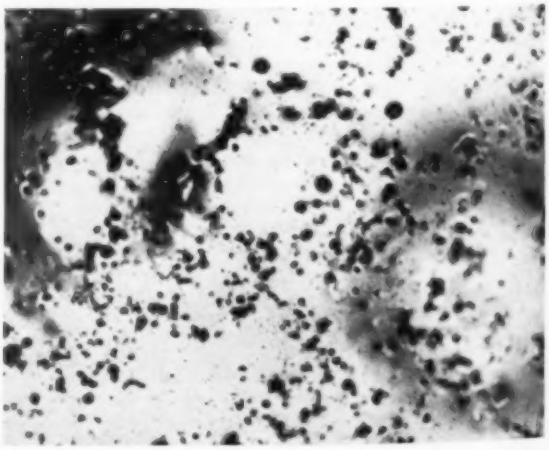

Fig. 5.—Electro-polished for 15 seconds at 48 volts and 9 amp./sq. cm. ×200

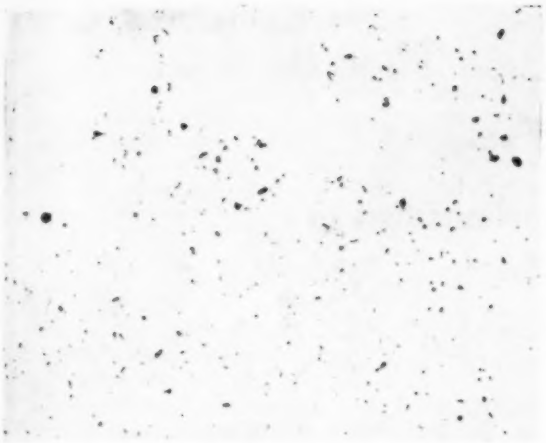

Fig. 6.—Mechanically polished, using <1μ diamond powder with white spirit on a revolving Selvyt pad. × 200

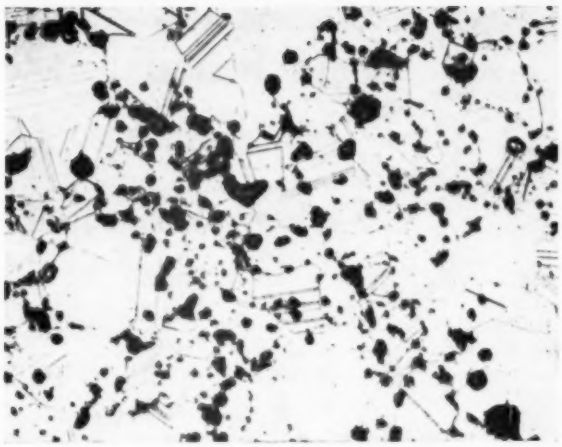

Fig. 7.—Electro-polished and electro-etched. × 200

which finish was true from these comparisons. Preferential attack at pores may have occurred in the case of the electro-polished specimen. It is equally likely that metal removed in the abrasive method may have filled pores, and the edges may have burred, thus giving an impression that pores are smaller than in fact.

Electro-etching

With most polishing electrolytes, etching occurs at lower voltages than those required for polishing.[14] Specimens which had been electro-polished in the manner described could not, however, be electro-etched with the same electrolyte. Similarly, the hydrogen peroxide/hydrochloric acid "swab" etch failed to attack the surface, and it was concluded that this had become passivated as a result of electro-polishing. Another solution was therefore used. This was unsuitable for electro-polishing, but satisfactory etching results were obtained when the following conditions were observed.

Surface Preparation.—After electro-polishing, specimens were immediately rinsed with water and etched without drying.

Electrolyte.—940 ml. distilled water
45 ml. nitric acid (technical grade)
15 ml. hydrochloric acid (technical grade)

Temperature.—Room temperature.

Cathode.—Stainless steel or Vitallium strip.

Supply.—Direct current from low tension batteries.

Voltage.—3·5 volts across the cell during etching.

Current Density.—0·75 amp./sq. cm.

Time.—15 seconds.

Film.—An orange film formed on the surface of the specimen during etching. This was readily removed with a water rinse. The specimen was then ready for examination after washing with alcohol and drying with hot air.

Examination

Fig. 7 illustrates a piece of the sintered alloy which had been prepared using the polishing and etching techniques described. Although pore sizes were slightly larger, the surfaces resulting from these treatments were free from the undesirable effects noted when abrasive polishing and "swab" etching techniques were employed. The methods described were therefore accepted as suitable for the metallographic work envisaged with this alloy.

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Contract for Davy-United

A FURTHER order for rolling mill auxiliary equipment, amounting to nearly half-a-million pounds in value, has been placed with Davy and United Engineering Co., Ltd., of Sheffield, by Dorman Long (Steel), Ltd. The equipment ordered is required for Dorman Long's new Lackenby Works, and comprises two primary cooling banks of reciprocating type, complete with pull-on-and-off gear, approach and run-out roller tables, and a scrap transfer bank. These two cooling banks, each approximately 90 ft. × 120 ft., are designed to handle hot rolled steel joists from 6 × 4 in. up to 36 × 16½ in. produced on the new broad flange beam and heavy section mill now being installed at Lackenby. In addition to a considerable amount of other auxiliary equipment, Davy-United are already building for Lackenby a 52 × 112 in. blooming and slabbing mill, which will be the largest mill of its type yet put into service in this country.

Renfrew Foundries, Ltd.

HIGH DUTY ALLOYS, LTD., announce that they have acquired the gravity and pressure die cast foundries operated by Renfrew Foundries, Ltd.

Liquid-Liquid Extraction Procedures in Inorganic Analysis

A Review of Practical Applications with Particular Reference to Metallurgical Analysis

By T. S. West, B.Sc., Ph.D., A.R.I.C.

Department of Chemistry, University of Birmingham

The growing complexity of modern materials has led to difficulties in their chemical analysis resulting from the increasing multiplicity of other substances accompanying the constituent to be determined. The development of new separation methods has made possible the continued use of classical analytical procedures in the face of increasing competition from physical methods, and in the present series of articles the author surveys liquid-liquid solvent extraction techniques in inorganic analysis, with particular reference to metallurgical analysis. In the fourth of the series, the author discusses the extraction of Group IV metals.

(*continued from page* 188 *of the April issue of* METALLURGIA)

EXTRACTION OF GROUP IVa METALS (Ti, Zr, Hf, Th)

Titanium

TITANIUM is not extracted to any measurable degree from hydrochloric acid solution by diethyl ether, and only negligibly small amounts are extracted from nitric acid solution. According to Fischer and Bock[42] small amounts (2·4%) are extracted from solutions containing a considerable excess of ammonium thiocyanate, and it would appear that virtually no extraction occurs from hydrobromic or hydriodic acid solutions. As far as is known, titanium cannot be successfully extracted as an inorganic compound from aqueous solution by organic solvents.

Dithizone is ineffective in extracting titanium or any of the other metals in this group from aqueous solution, but the titanium chelates with 8-hydroxyquinoline and cupferron can readily be extracted. An interesting variation of the 8-hydroxyquinoline method has been proposed by Gardner[65] who observed that the colour of the oxine extract of a titanium solution was considerably intensified in the presence of hydrogen peroxide, and that this colour was more intense than that of the peroxide complex of titanium. It was suggested that the titanium compound extracted is a peroxidised oxinate. At *p*H 3, aluminium is only slightly extracted, but iron and molybdenum are removed completely and vanadium and zirconium are partially extracted. Between *p*H 2·5 and *p*H 5, titanium is transferred completely to the organic phase. Furman, Mason and Pekola[17] found that the titanium cupferron chelate is more soluble in chloroform than in ether, and that it may be completely extracted from 10% hydrochloric acid by either solvent or by ethyl acetate: Miller and Chalmers[45] favoured the use of *o*-dichlorobenzene for the extraction.

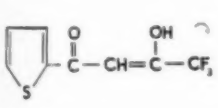
Zirconium and Hafnium

Zirconium is not extracted by diethyl ether from hydrochloric acid solution, but according to Bock and Bock[66] appreciable amounts (*ca* 8%) are removed by ether from 50% nitric acid. Chalybaeus, Zumbusch and Fischer[67] studied the separation of zirconium and hafnium by solvent extracting the zirconium from an acidified solution containing thiocyanate, and found that the extraction method compared favourably with fractional crystallisation, precipitation, and volatilisation methods. Kitahara[36,37] reports that zirconium is not extracted from either hydriodic acid or hydrofluoric acid by diethyl ether.

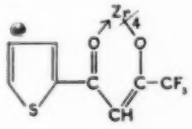
One of the most recent studies in the solvent extraction of zirconium has been concerned mainly with its separation from niobium. The authors, Scadden and Ballou,[61] examined several systems. It was found that acetyl acetone extracted neither metal from 0·7M hydrochloric acid, and that chloroform was equally ineffective in extracting them from a trichloroacetic acid medium 0·5M in sulphuric acid. On the other hand, while diethyl ether did not remove zirconium from 5M ammonium thiocyanate solutions made 1–4M with respect to hydrochloric acid and containing 0·05M oxalate, approximately 30% of the niobium was extracted. Ethyl acetate containing 0·01M β-nitroso-α-naphthol extracted 60% niobium, but no zirconium from 1–8M hydrochloric acid. Partial extraction of both zirconium and niobium occurred when mandelic acid and amyl alcohol were used to extract solutions 0·002M in oxalate ion at *p*H 2. No extraction occurred when *m*-nitrobenzoic acid was used in amyl alcohol or isobutyl acetate, but when tributyl phosphate was used as solvent for the nitrobenzoic acid, 15% and 5%, respectively, of zirconium and niobium were extracted. Scadden and Ballou found that a 0·06M solution of di-*n*-butylphosphoric acid in di-*n*-butyl ether was far superior to the other systems, removing at least 99% of the zirconium from 1M mineral acid (nitric, perchloric, hydrochloric or sulphuric) and 0·004M oxalic acid and leaving 98% of the niobium in the aqueous phase. Additions of hydrogen peroxide (3%) reduced the niobium contamination to 1%. The lower the concentration of mono-*n*-butyl phosphoric acid in the reagent, the less niobium is extracted, while the

zirconium is still virtually completely removed from the aqueous solution. A much stronger reagent solution (viz., 0·6M) extracts both metals—99% zirconium and 95% niobium from 1M acid and 0·004M oxalate solution. In dealing with macro concentrations of the metals (1 mg./ml.) it was found that a 15 minutes extraction by an equal volume of 0·06M reagent removed 99% zirconium and 5% niobium from 1M sulphuric acid made 2·5M with respect to ammonium sulphate and 6% in hydrogen peroxide. By reducing the mono-butyl acid concentration in the reagent to 0·0003M, 98% removal of zirconium occurred and 1% of niobium. Using the 0·6M, reagent, the authors found that in the absence of peroxide 99% zirconium and 98% niobium were extracted in 5 minutes, and in the presence of 6% peroxide 93% of the niobium was still extracted. Large amounts of tin (50%) and tantalum (35%) are removed and virtually complete extraction of indium, iodine, holmium, and yttrium occurs with the 0·6M reagent, whilst cæsium, strontium, lanthanum, silver, cadmium, germanium, selenium^{IV}, tellurium^{IV}, antimony$^{III \text{ and } V}$, arsenic^{V}, palladium, ruthenium, rhodium, molybdenum and cerium^{III} are scarcely extracted. The 0·06M reagent extracts moderate amounts of tin^{IV} (15%) and large amounts of indium (85%) and iodine (>95%). Back extraction of the zirconium from the extract was accomplished by shaking with 4M hydrofluoric acid.

Zirconium and hafnium form extractable complexes with the 1, 3 diketone-thenoyltrifluoroacetone (T.T.A.).



α–Thenoyltrifluoroacetone



Zirconium chelate

These are readily soluble in benzene, and extraction occurs favourably from 2M perchloric acid solution. Two extractions with a 0·025M solution of T.T.A. in benzene of a solution containing 59% as much zirconium as hafnium yield 27% of the hafnium with a content of less than 1·2% zirconium. The equilibrium constants were found to be $9{\cdot}4 \times 10^7$ for the extraction of zirconium from 2M perchloric acid and $4{\cdot}6 \times 10^6$ for hafnium[68,69]. A fractional separation of zirconium and hafnium is therefore possible by this method. Schultz and Larsen[70] have also examined the fractional separation of zirconium and hafnium by solvent extraction with a benzene solution of trifluoroacetone in benzene. The zirconium is preferentially extracted into the benzene phase as the chelate compound tetrakis-(1, 1, 1-trifluoro-2, 4-pentanediono)-zirconium in a manner similar to that observed in the extraction of zirconium from perchloric acid solution. The extraction coefficient is dependent on the metal ion concentration, decreasing as the latter increases. This is consistent with the hypothesis that the monomeric zirconium ion is in equilibrium with a polymeric species. Assuming that only the monomeric ion reacts with the diketone, then the equilibrium must shift to increase the concentration of the extractable species on dilution. Evidence for the existence of a non-extractable metal ion was found from data on the repeated extraction of an aqueous zirconium solution. The extraction coefficient diminished steadily, yet when the metal was precipitated by ammonia between extractions and redissolved in hydrochloric acid, consistent values for the extraction coefficient were found. Considerable complexing action by the chloride ion was observed even in 0·2M hydrochloric acid, but it was noted that the chloride ion complexing of hafnium was much more marked than that of zirconium.

Using the trifluoroacetone reagent in benzene, to extract zirconium from 0·2M hydrochloric acid solution, Schultz and Larsen found that in two extractions the molar percentage of hafnium in a zirconium-hafnium mixture could be reduced from 1·56 to <0·1–0·05, with 6·9% yield of the original zirconium. In six extractions the molar percentage of hafnium in a zirconium/hafnium mixture was increased from 7·5 to 99·9% with 37·6% yield of the original hafnium. In purifying the benzene extracts containing zirconium, the organic phase was shaken three times with an equal volume of 4·8M hydrochloric acid.

With the 0·02M T.T.A. reagent in benzene, Huffman and Beaufait[69] recorded that in 2M perchloric acid containing 22·9 mg. hafnium and 13·6 mg. zirconium in 150ml, two extractions with equal volumes of reagent left 0·31 mg. hafnium in the aqueous phase. In 300 ml. of 2M perchloric acid containing 78·6 mg. hafnium and 3·93 mg. zirconium, three extractions gave a recovery of 39·4 mg. of hafnium containing only 0·4% zirconium.

In their review of the extraction of cupferrates, Furman, Mason and Pekola[17] note that the zirconium chelate is readily soluble in ethyl acetate.

Thorium

Thorium is not extracted from hydrochloric acid by diethyl ether, nor would it appear to be extracted from hydriodic or hydrobromic acid solutions. Only trace amounts are removed by ether from a solution containing a large excess of ammonium thiocyanate.

The behaviour of thorium nitrate in its extraction from nitric acid solution by various solvents and in the presence of various salting-out agents presents rather a complex picture.[66] Virtually no extraction of thorium occurs at acidities less than 4N, while at 8N the value rises to *ca* 34% when diethyl ether is used as solvent. The presence of lithium nitrate in the aqueous phase favours the extraction of thorium to such an extent that approximately 56% is extracted by diethyl ether from 1M nitric acid saturated with lithium nitrate, yet neither sodium, potassium nor ammonium nitrates promote the extraction. Calcium nitrate also favours the extraction (57%), while strontium nitrate (0·18%) and barium nitrate (0·08%) have little effect. Zinc ions have the remarkable power of increasing the percentage extraction to 81%, whilst ferric nitrate promotes 74% extraction and magnesium nitrate is moderately efficient at 44%. Ethyl acetate, methyl *n*-propyl ketone, iso-butyl methyl ketone and diethyl ketone are excellent solvents for the extraction, whilst amyl alcohol and di-*n*-propyl ketone are also suitable. Diethyl ether is much less efficient, but it is remarkable that both diisopropyl ether and dichlorodiethyl ether (much used in the extraction of ferric chloride) extract scarcely any thorium from aqueous solution. Tributyl phosphate (T.B.P.) is extremely efficient in extracting thorium, and its use in separating thorium from cerium has already been discussed. Peppard and his co-workers have isolated gram amounts of thorium 230 from pitchblende by extracting the nitrate solution of the mineral with T.B.P. The thorium 230 was separated from the accompanying scandium, yttrium,

etc., by shaking the extract with aqueous hydrofluoric acid, when the thorium passed almost completely into the aqueous phase as the insoluble fluoride.

The thorium salt of cupferron is very soluble in ether, but difficultly so in chloroform. Ethyl acetate gives almost complete removal of thorium cupferrate from 10% hydrochloric acid. The thenoyltrifluoroacetone (T.T.A.) complex of thorium can readily be extracted into benzene from a nitric acid solution buffered at *p*H 2·5. Meinke and Anderson[71] used this to separate gram amounts of thorium from actinium and radium isotopes present in tracer amounts after cyclotron bombardment of the thorium. In a specially designed continuous extractor operated by remote control, the thorium was extracted at a rate of 1 g. per 3 hours. The thorium was back extracted into an aqueous phase by shaking the benzene extract with 2M nitric acid. A solution less acid than *p*H 2·5 still allows of chelation, but other products are extracted along with the thorium. Hagemann[72] has studied the extraction of actinium by T.T.A. in benzene, achieving a separation from radium by a controlled *p*H method. He also studied the extraction of thorium, lead, bismuth, and thallium[I and III] by T.T.A. and benzene.

EXTRACTION OF GROUP IVb METALS (Sn, Pb, Ge)

Tin

Diethyl ether extracts moderate amounts of stannous tin (15–30%) and also of stannic tin (17%) from 6N hydrochloric acid solution. Although no definite information could be found on the extraction of this metal from hydrobromic acid solution, it is almost certain that extraction would be more favourable than from hydrochloric acid. Kitahara[36] has reported quantitative extraction of stannous iodide from 6·9N hydriodic acid by diethyl ether, and Irving and Rossotti[38] have shown that extraction is quantitative even from 1·5N acid. It has also been reported that both stannous and stannic tin are quantitatively removed from hydrofluoric acid solution by the same solvent.[37] Tin[IV] is completely extracted from 10% hydrofluoric acid: extraction of tin[II] is complete only in acid not weaker than 40%. West and Carlton used methyl isopropyl ketone as solvent for extracting the iodide.

Stannic cupferrate is very soluble in chloroform, and extraction from 10% hydrochloric acid is complete when ethyl acetate is used as solvent for the chelate. The corresponding stannous complex is also known to be soluble in non-polar solvents such as benzene and chloroform.[17] According to Gentry and Sherrington,[16] stannic tin is extracted from solutions buffered in the *p*H range 2·5–5·5 by a 1% solution of oxine in chloroform. The extraction is incomplete in the presence of tartrate. Stannous tin may similarly be extracted using a solution of dithizone in chloroform or carbon tetrachloride. The *p*H must be greater than 4, the optimum conditions being *p*H 6–9 for carbon tetrachloride. Unfortunately the extract is unstable.[29] Stannic tin may possibly be extracted by chloroform as the compound formed with the tetraphenylphosphonium ion, i.e., $((C_6H_5)_4P)SnCl_6$ according to Willard and Perkins,[73] but no details are given.

ETHER EXTRACTION OF METALS FROM AQUEOUS HYDROFLUORIC ACID SOLUTION.[37]

Metal	% Acid Concentration	% Extraction
Tin IV.	0	0
	10	100
	20	100
	40	100
Tin II.	10	0
	20	8·6
	40	100
Arsenic III.	20	44·5
	40	62·2
Antimony	20	0·4
Molybdenum*	30	9·7

* A solution of MoO_3 in 30% hydrofluoric acid.

Nickel, chromium, cobalt, manganese, potassium, titanium, zirconium, gallium, silver, uranium, bismuth, tellurium, cadmium, osmium, platinum, palladium, iridium, ruthenium and vanadium (as $NaVO_3$) were not extracted to any measurable degree. 0·7% of selenium was extracted from neutral solution, and 3·1% from 40% hydrochloric acid.

Lead

Lead is not extracted from hydrochloric acid solution by diethyl ether, and only trace amounts are extracted from 8N nitric acid. No information could be found on extraction from hydrobromic or hydrofluoric acid solutions. West and Carlton[40] have made a detailed study of the extraction of lead as iodide by methyl isopropyl ketone. The extraction takes place readily from acid solution. Other metals forming iodides which are at least partially extracted are tin, mercury, iron, antimony, copper, palladium, cadmium, rhodium, gold and ruthenium. Fortunately most of these ions can be removed by a preliminary extraction with the solvent from thiocyanate or hydrochloric acid media. The aqueous layer then treated with potassium iodide gives up lead, cadmium, and ruthenium to another extraction with methyl isopropyl ketone. Iron, copper, zinc, mercury, gold and palladium can be completely extracted as their thiocyanates from an acid solution containing an excess of ammonium thiocyanate, whilst tin and antimony are extracted as chlorides. Lead iodide is incompletely extracted from neutral solution, but completely so from 5% v/v hydrochloric acid. Other solvents examined for this extraction were butyraldehyde, *n*-amyl alcohol, methyl *n*-amyl ketone, methyl isobutyl ketone, methyl *n*-propyl ketone, and ethyl acetate. The extraction of lead does not produce a highly coloured organic phase.

Lead can be extracted from solution by oxine or dithizone in chloroform. According to Sandell,[29] the optimum conditions for extracting the dithizone compound by chloroform lie within the *p*H range 8·5–11. In the presence of cyanide, the only other dithizonates extracted are those of bismuth, thallium, and tin.[11] Lead cupferrate is not extracted by organic solvents. The diethyldithiocarbamate may be extracted with ethyl acetate or chloroform.[74].

Germanium

Germanium is so readily separated from other materials by distillation of the tetrachloride from 50% hydrochloric acid, that little attention seems to have been paid to its isolation by solvent extraction procedures. Diethyl ether will, however, extract 40–60% of the germanium content of a 6N solution of hydrochloric acid, and some 2% is extracted as GeO_2 from 50% nitric acid by the same solvent. No information appears to be available on its extraction from the other halogen acids or from thiocyanate solution. As far as is known, germanium is not extracted by dithizone, oxine, or cupferron in chloroform. The extraction of germanium as molybdogermanic acid has been examined by Wadelin and Mellon,[75] but they were mainly concerned with the extraction of the molybdophosphoric acid.

(*Continued on page* 240)

Reproducibility in the Spectrographic Analysis of Aluminium Alloys

By F. H. Smith

Development Officer, ALAR, Ltd.

This note summarises the results of an investigation of the precision of the spectrographic method in the routine analysis of aluminium alloys. It is part of a programme undertaken by the ALAR Spectrochemical Sub-Committee, on whose behalf it is presented, and is based on the results submitted by four laboratories, all of which use the spectrograph as a routine inspection tool.

THE advantages of the spectrographic method of analysis—for example: speed, simplicity and the provision of a permanent record—have led to the general adoption of the instrument in the light alloy industry, where it has now been in use for some twenty years. It is surprising, therefore, that so little has been written of the precision and accuracy of the spectrograph in routine analysis. Reproducibility has been graphically illustrated previously,[1,2] but not on the basis of a comprehensive investigation of the kind reported here. Standard deviation values published from time to time have mainly been obtained under research laboratory or specially controlled conditions. Mills and Hermon[3] and D. M. Smith,[4] for example, quote coefficients of variation for results obtained in investigations on electrode forms and tip shapes, and Walsh[5] gives similar data obtained in the development of a source unit. Analytical "tolerances" for a range of elements in various alloys are given in the only British book[6] dealing exclusively with the spectrochemical analysis of aluminium alloys, but the basis on which these values were calculated is not stated. Similarly, the A.S.T.M. quotes the precision of its tentative standard method[7] in "repeat tests" equivalent to coefficents of variation of 2–4% for concentrations above 0·5%, with higher values for smaller contents. Again it is not clear whether this precision relates to repeat tests on the same plate or to a number of separate tests made at approximately the same time, or whether the results on which the precision was assessed were collected during the course of many weeks, and so include the effects of the many variables over which it is impracticable to maintain absolute control in routine analysis.

Finally, the increasing interest which is being shown in direct reading instruments has led to the inclusion of values for the coefficients of variation by these methods in papers[8,9] describing the use of the instruments. Such values do not, of course, afford evidence of the precision to be expected from the simpler, and as yet more widely used, photographic method, but reference is made to them later by way of comparison.

Scope of the Investigation

For a number of years the ALAR Spectrochemical Sub-Committee has operated a system of analysing exchange samples distributed among its members. This has been described elsewhere,[1,10] but it is necessary to emphasise here one essential feature of the scheme, namely, that the samples, which are in the form of electrodes, are included in batches of ordinary routine production samples, and treated exactly as routine tests. From most exchange series, one sample, selected as permitting the maximum number of elements to be determined, has been analysed repeatedly, mostly some fifty times, by each member. This particular sample has been included in batches of routine samples and appropriate standards, and has been sparked, photographed, and evaluated without special distinction. By analysing these samples not more than once each day, the total period over which the fifty determinations were made was extended to 8–10 weeks. It was thought, by this method, to cover in some measure those day-to-day variations which cannot be avoided in production spectrochemical analysis, and so to obtain data which would truly represent the order of agreement to be expected when the method is used by different laboratories and over a period of time. In the course of the investigation, some ten thousand determinations were made.

During the period in which the data for this note were collected, all the participating laboratories were using Hilger Medium Quartz Spectrographs and a simple condensed spark circuit, usually with an added inductance of 0·13 mh, but in a few cases, 0·25 mh. Cast pencil electrodes were sparked in pairs by all but one member, who used a graphite pencil in a point-to-plane system. The common photographic plates, development and practice were employed, with only small differences between one laboratory and another, and in general the evaluation of the spectra followed the usual pattern, all members using the Hilger microphotometer.

Most of the series were analysed before ALAR spectrochemical standards were available (the exception is LM4), and each laboratory used its own standards for each alloy. In the light of the recently published note[11] on segregation in electrodes, it is possible that heterogeneity in the electrode samples or the standards would have some effect on the order of reproducibility of the analytical results. In each series, each electrode was sparked, remachined and resparked to give 50 results in duplicate, whereas in normal routine practice pencil electrodes are sparked once or twice only, at a fixed distance from the end of the pencil, and in the case of flat electrodes sparking is confined to a certain position and depth from the surface. Examination of the results from 50 consecutive sparkings with single pairs of pencils, however, has not revealed any trend in apparent com-

TABLE I.—COEFFICIENTS OF VARIATION (per cent)*

Alloy	Laboratory	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti
LM12		—	(0·28%)	—	(0·60%)	(0·26%)	(0·21%)	(0·08%)	—	—	(0·04%)
	A	—	5·3	—	4·2	5·6	5·3	7·7	—	—	8·8
	B	—	5·5	—	4·4	4·3	5·9	—	—	—	—
	C	—	5·9	—	3·8	5·3	—	—	—	—	—
	D	—	5·9	—	5·6	7·4	6·8	15·5	—	—	7·8
LM6/20		(0·13%)	(0·09%)	(10·5%)	(0·52%)	(0·22%)	—	(0·09%)	—	—	—
	A	—	6·6	4·2	4·3	6·5	—	7·8	—	—	—
	B	—	12·5	—	4·7	4·8	—	11·3	—	—	—
	C	—	4·9	13·7	—	4·3	—	—	—	—	—
	D	9·4	13·4	—	6·7	7·4	—	11·1	—	—	—
LM4/21		(2·3%)	(0·10%)	(5·7%)	(0·78%)	(0·65%)	(0·24%)	(0·25%)	(0·11%)	(0·12%)	(0·09%)
	A	—	6·1	—	4·7	3·4	8·3	5·4	6·4	6·5	11·0
	B	8·7	7·8	3·9	4·9	5·1	8·5	4·8	—	—	6·1
	C	—	5·5	—	3·5	4·5	7·5	—	—	—	—
	D	6·1	3·0	4·7	5·1	5·2	5·4	2·9	8·1	14·2	7·0
LM6/20		(0·07%)	(0·10%)	(12·6%)	(0·47%)	(0·32%)	(0·10%)	(0·11%)	(0·06%)	(0·08%)	(0·07%)
	A	—	5·0	—	4·4	3·9	7·2	6·3	10·0	8·3	7·2
	B	6·2	5·8	3·5	2·8	2·2	5·3	9·2	—	—	5·7
	C	8·2	6·9	—	3·8	—	10·8	—	—	—	—
	D	5·4	9·1	—	5·7	6·6	10·4	9·5	21·0	20·0	8·9
LM2		(1·83%)	(0·19%)	(8·6%)	(0·77%)	(0·47%)	(0·33%)	(0·33%)	(0·13%)	(0·13%)	(0·14%)
	A	—	4·9	4·0	5·4	3·7	9·8	6·8	5·6	8·0	9·9
	B	11·5	7·5	4·8	5·8	3·3	7·9	5·2	—	—	7·7
	C	5·3	—	3·0	3·9	4·2	5·6	8·6	—	—	6·9
	D	5·4	9·1	4·3	5·6	8·2	7·6	4·7	7·9	—	6·3
LM1		(7·4%)	(0·19%)	(2·5%)	(0·58%)	(0·52%)	(0·19%)	(1·8%)	(0·22%)	(0·11%)	(0·03%)
	A	—	8·6	—	4·0	5·0	8·4	—	5·9	8·3	11·0
	B	6·1	5·7	—	3·7	3·8	7·6	—	—	—	—
	C	—	7·5	5·8	4·7	6·1	7·4	9·4	—	—	23
	D	—	7·1	4·1	8·2	5·8	9·8	4·9	7·6	13·7	13·8
D.T.D.479		(3·4%)	(0·62%)	(0·65%)	(0·46%)	(0·74%)	(0·13%)	(0·08%)	—	—	—
	A	—	7·0	8·4	7·7	4·2	11·8	11·4	—	—	—
	B	—	9·2	7·1	10·7	11·4	—	8·2	—	—	—
	C	—	4·5	4·8	5·3	3·2	—	—	—	—	—
	D	3·4	9·0	8·3	6·7	6·2	9·4	16·5	—	—	—

*The nominal contents are shown in brackets.

position variation which could conclusively be attributed to this cause. With the flat electrode, it was possible to restrict sparking to that portion over which it has been shown[11] that the effect of the small variations in composition can be overcome.

Consideration of Results

As the results of only single laboratories are contained in any one of the histograms or coefficients of variation figures, differences in calibration arising from the use by participating laboratories of their own, instead of common, standards have no effect on the reproducibility of the results, but will of course have a bearing on the accuracy of the determinations.

It was considered worthwhile to draw histograms from each member's results for all the elements which had been determined. In the course of time, most of the more common casting alloys were included in this scheme, the limitation being the availability of standards for ranges of element contents which are not usually analysed spectrographically as routine practice. A few of these histograms have been selected to illustrate their general form and appear in Fig. 1. If allowance is made for the comparatively small number of observations, it will be seen that the histograms tend towards the normal or random distribution, and that the scatter is not unduly wide.

Whilst the histograms have been of interest, their main purpose has been to show that the distribution justified the calculation of standard deviations from the results. The coefficients of variation based on these deviations are given in Table I for six alloys and up to ten elements. The nominal contents are shown in brackets and cover approximately the range 0·05 to 10%. On the whole, the agreement between the four laboratories is satisfactorily close, and only in one or two instances is the scatter wide.

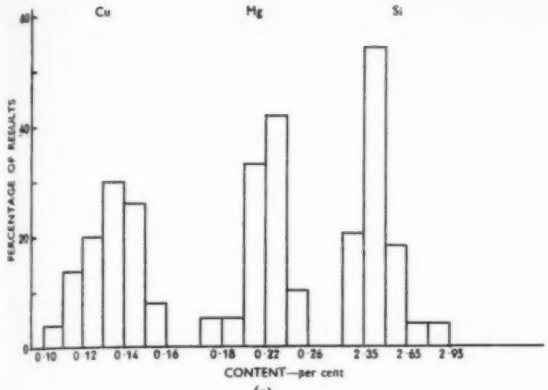
The order of reproducibility can be more easily seen when the data for Table I are presented graphically. In Fig. 2 the average coefficients of variation have been plotted against content, irrespective of element. The curve so obtained shows that the reproducibility falls off with decreasing content, as was previously[10] found for chemical analysis results, and that the coefficient of variation is approximately 4% for a content of 10%, 5% for 1%, 8% for 0·1%, and probably 20% for a content of 0·01%.

Striking confirmation of the form of this curve is provided by results obtained completely independently, and kindly made available by the spectrographic laboratories of High Duty Alloys, Ltd.[12] These were obtained from routine analysis of seven elements in two aluminium alloys, RR50 (LM7) and Hiduminium 20 (LM4), the number of determinations per element varying from 12 to 32. These values, shown by small triangles, have been superimposed upon the curve in Fig. 2, and can be seen to fit remarkably closely.

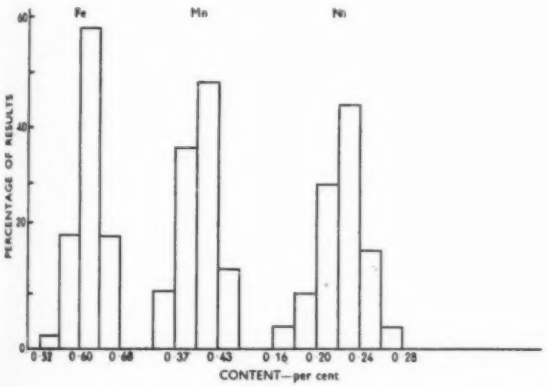
Comparable data for the reproducibility of results from routine chemical analysis methods, see Curve A, Fig. 3, indicates that the spectrographic method gives a little greater precision for contents below 0·3% and that the chemical method is superior at higher contents. In considering this comparison, it should be borne in mind that, in order to take full advantage of the spectrographic method, it is usual to determine all the desired elements from one spectrum, produced under electrical and other conditions which are a compromise of the ideal conditions for the individual elements. If the best conditions for a particular element were employed, it should be possible to increase the precision for that element.

Comparison with Quantometer

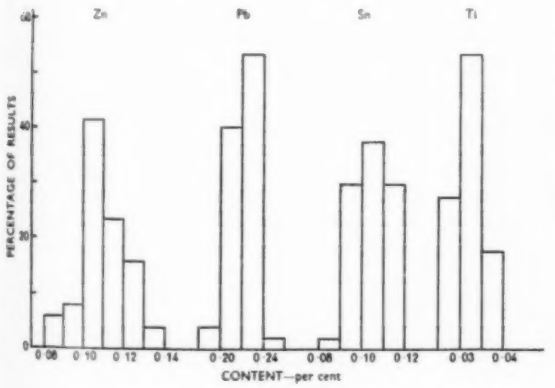
The spectrographic results presented in this brief note ave been derived from the evaluation of the spectrum



(a)



(b)



(c)

Fig. 1

recorded on a photographic plate. It is interesting to see how they compare with those obtained using a direct reading instrument such as the Quantometer, where the photographic and some of the personal sources of error are avoided. Callon and Charette[9] give standard deviation values for a wide range of elements and contents, and these have been plotted for comparison in Fig. 3, Curve C. These data are not strictly comparable with the results of the present investigation for several reasons. It is not clear in all cases how the figures were obtained on which Callon and Charette base their coefficients of

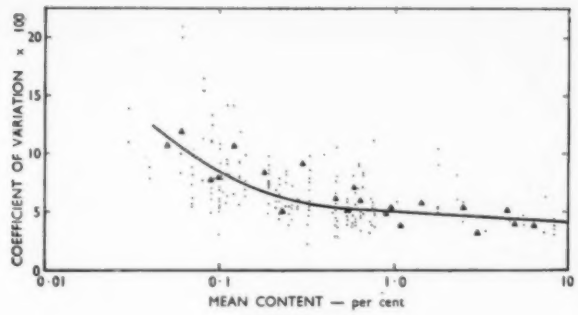


Fig. 2

variation, but it appears that some at least were produced under conditions approaching those of research laboratory work. The instrument used was a Research Quantometer, whereas for routine work it is usual to employ a Production Control Quantometer. Further, the alloys and types of standards and electrodes are different from those used in the present work, and the results are all obtained by one laboratory.

In spite of this, there is reason to believe that the coefficients of variation reported by Callon and Charette do represent approximately the *order* of precision obtainable in routine analysis. One member of the ALAR Sub-Committee, who for some time has been using the Production Control Quantometer, has reported that generally similar, if somewhat higher, coefficients of variation to those found by Callon and Charette have been obtained.

The curve for the Quantometer results (see Fig. 3) runs roughly parallel to the one based on spectrographic results for the higher contents, but rises less steeply when the amount of the element determined is very small. Because of the different conditions under which the two sets of data were obtained, it might be misleading to compare the reproducibilities quantitatively, but it is nevertheless quite apparent that for routine determinations the order of reproducibility of the direct reading instrument is considerably higher than that obtained using the simpler instrument and photographic recording. Furthermore, this difference is not significantly diminished if the comparison is made with the results of one instead of the four spectrographic laboratories.

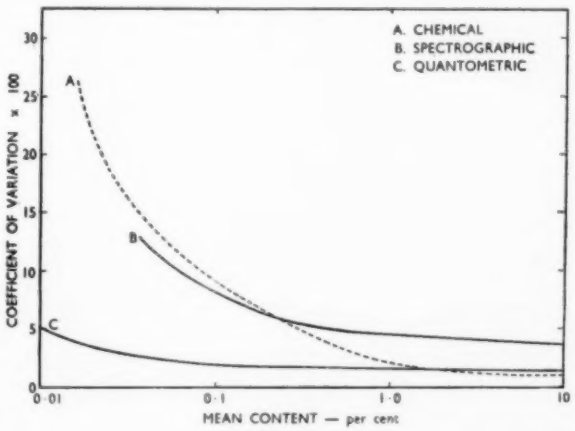


Fig. 3

This comparison with the Quantometer is an interesting sidelight, but the main purpose of this article is to provide an indication of the order of reproducibility obtainable in the routine analysis of aluminium alloys using the medium quartz spectrograph with photographic plates and photometer. The results confirm that in addition to any advantages the use of the spectrograph may show, such as a saving in operating time, it is capable of giving routine results with a reproducibility approaching that of chemical methods for the composition ranges of most aluminium alloys, and of giving greater precision for low contents.

Acknowledgment is due to Mr. E. C. Mills of High Duty Alloys, Ltd., who kindly supplied the independent data shown in Fig. 2.

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Research and Nickel-Plating

Some Aspects Reviewed in Hothersall Lecture

At the Annual Conference, held at Blackpool, Dr. Wesley, Manager of International Nickel's Research Laboratory at Bayonne, New Jersey, was awarded the 1955–56 Hothersall Memorial Medal by the Institute of Metal Finishing, for his outstanding work in the field of electro-deposition.

In the Hothersall Memorial Lecture, which accompanies the presentation, Dr. Wesley took as his subject "Of Nickel Atoms, Ions and Electrons." The speaker applied recent theories of the electronic structure of the transition elements to explain the mechanism of dissolution of nickel, with particular reference to the industrial practice of nickel-plating, a process of considerable commercial significance in the metal finishing industry.

A basic part of the nickel-plating process is the electrode reaction by which nickel dissolves, Dr. Wesley said, adding that this reaction is also significant because it is the primary step in the corrosion of nickel alloys. In spite of the importance of the reaction, the mechanism by which it takes place is not fully understood, and the behaviour of nickel as demonstrated by its polarisation curves requires more explanation. In a field somewhat remote from electrochemistry, namely, that of solid state physics, recent advances have brought forth new ideas regarding the electronic structure of metals. These ideas have given Dr. Wesley what he believes to be the key to an explanation of the behaviour of nickel anodes in nickel-plating.

He proposed in his lecture a theory that the electronic structure of the nickel atom, as it is believed to exist in the metallic state, plays a decisive part in the mechanism of the reaction by which nickel dissolves. If the three kinds of nickel atom cores which exist in nickel metal require different energies of activation for reaction, then this can be used to explain most of the unusual features of the behaviour of nickel anodes which have puzzled electrochemists for decades. The theory should also lead to new developments in the practical as well as the scientific aspects of the nickel-plating process. It is expected to stimulate research in the field of corrosion, and there is reason to believe, Dr. Wesley remarked, that some puzzling features of the corrosion and passivity of not only nickel but other metals and alloys will be explained when they are examined in the light of his theory.

The Hothersall award was established by the Institute of Metal Finishing in 1953 in memory of the late A. W. Hothersall. The recipient is given the Hothersall Memorial Medal, a palladium medal endowed by The Mond Nickel Company Limited. Dr. Wesley is the third recipient of the medal. The first was Dr. G. E. Gardam of Aluminium Laboratories, Ltd., Banbury, and late Director of the Design and Research Centre for the Gold, Silver and Jewellery Industries, in London. The second was Dr. William Blum, retired head of the Electrochemical Division of the National Bureau of Standards in Washington, D.C.

N.P.L. Open Day

The National Physical Laboratory, Teddington, is holding an Open Day on Friday, May 25th. Admission is by ticket only and a limited number of invitations for the afternoon period, 1-30–5-30 p.m., are still available on application to the Director.

Liquid-Liquid Extraction Procedures in Inorganic Analysis

Continued from page 236

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